SIMULATION OF URBAN HYDROLOGIC SYSTEMS USING ILLUDAS

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In Partial Satisfaction of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

By

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to the

DEPARTMENT OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

MAY, 1979

CE-1979-M-SIN-SIM

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MY PARENTS

CERTIFICATE

This is to certify that the thesis "Simulation of Urban Hydrologic Systems Using ILLUDAS" submitted by Sri Kripal Singh in partial fulfilment of the requirements for the degree of Master of Technology of the Indian Institute of Technology, Kanpur, is a record of bonafide research work carried out by him under our supervision and guidance. The work embodied in this thesis has not been submitted elsewhere for a degree.

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LIST OF SYMBOLS, ABBREVIATIONS , OR NOMENCLATURE

A	Area of the basin
C	Coefficient of runoff
e	Base of natural logarithm
f_o	Initial infiltration rate
f_c	Final infiltration constant rate
I	Intensity of rainfall
K	A shape factor
L	Length of overland flow
n	Manning's roughness coefficient
Q	Peak discharge
S	Storage
t_e	Time of equilibrium
t	Time from start of rainfall
t	Time interval

ABBREVIATIONS

GA	Grassed area
GT	Grand Trunk
IDA	International Development Agency
IITK	Indian Institute of Technology, Kanpur
ILLUDAS	Illinois Urban Drainage Area Simulator
PASR	Paved Area Supply Rate
RRL	Road Reasearch Laboratory
SPA	Supplemental Paved Area
APARO	Supplemental Paved Area Runoff

SYNOPSIS

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With ever increasing urbanization in India there is a great and urgent need for rational economic design of urban drainage systems. Conventionally they are designed by empirical approaches including the rational formula. But the rational method has very serious limitations particularly where diversion from one catchment to another, flood storage, off channel storage, permanent storage, totally impervious catchment, and pumping installations are involved. In such cases it is very much necessary to use urban drainage simulation models for rational and economic design.

There are several computer simulation models available for simulation of urban drainage systems with different assumptions and capabilities. Based on a comparison of the capabilities of the model, their simplicity, availability of data, and a lack of interest in quality simulation, ILLUDAS, a model, developed by Illinois State Water Survey, was implemented in the IBM 7044-1401 Digital Computer System at

Indian Institute of Technology Kanpur and was validated with the test data available with original programme.

The programme was used to simulate storms of different durations and frequencies in four subsystem of Indian Institute of Technology Kanpur campus drainage system with areas varying from 34.0 to 135.0 acres. The study indicates that a storm of duration of about 30 minutes and a frequency of 2 to 5 years may be adopted for design of the systems.

A preliminary analysis of three subsystem of drainage systems respectively for the cities of Amritsar, Jullendhar, and Ludhiana indicated that the upper reaches of the system are to be designed for a duration of around 30 minutes and lower reaches are to be designed for a duration of 1 to 2 hours. A design frequency of 2 to 5 years may be adopted for the system for domestic areas and a higher frequency for commercial areas. It is necessary to identify directly connected paved areas, supplementary paved areas and contributing grassed areas for different reaches of the system before definitive decisions can be taken.

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1. INTRODUCTION

1.1 General

While India is essentially a developing country with a large rural population, the metropolitan and urban areas of India are growing rapidly. In 1971 the urban pupulation of India was around 110 million persons which correspond to 13 % of the total population (2). It varied from 7 % in Himachal Pradesh to 31 % in Maharashtra and these are much smaller than figures for developed nations such as U.K. with 80 % and U.S.A. with 70 % urban population. Calcutta, Bombay and Delhi are three of twenty five largest urban agglomerations of the world. Table 1.1 indicates the distribution and growth of the cities in India. Of the 2912 towns in India in 1971, 340 had a population of more than 50000. The rate of growth of urban population was 26 % over the 1951-1961 decade, 38 % over 1961-1971 decade and it is expected to be increasing currently at a higher rate. The total population of India is expected to increase from 547 million in 1971 to 1000 million by around the year 2000.

1.1.1 Urban drainage

When storm rainfall occurs in a rural area, much of it soaks into the earth, and the remainder runs off to

TABLE 1·1 : SOME CHARACTORSTICS OF THE URBAN POPULATION OF INDIA. (2)

POPULATION RANGE	NUMBER OF CITIES IN RANGE.			POPULATION IN RANGE MILLIONS OF PERSONS
	1971	1961	1951	
100,000 OR MORE	142	113	102	57·00
50,000 TO 100,000	198	138	102	13·20
20,000 TO 50,000	617	484	353	18·90
10,000 TO 20,000	931	748	630	13·10
5,000 TO 10,000	756	760	1,158	5·70
SUB TOTAL	2,644	2,243	2,324	107·90
LESS THAN 5,000	277	218	599	0·90
TOTAL	2,921	2,461	2,923	108·80

the nearest stream. The excess surface runoff may cause some temporary flooding on the land surface along ditches, drainage ways, and small stream channels. When the city is constructed, much of the natural land-scape is covered with rooftops, paved streets, and other paved areas. The remaining natural earth is usually covered with grass lawns. Thus urbanization increases the imperviousness of the watershed and hence reduces the imfiltration and other obstractions from storm rainfall. The complete transformation from rural basin to urban would increase the flood peak as well as total run off from the surface. This increase in flood peak may cause flooding of urban areas. In order to prevent flooding of urban catchment, it is necessary to provide a system of conduits to remove the runoff efficiently. This process of removing runoff from urban areas is called urban drainage and the system is called an urban drainage system.

1.1.2 Urban drainage network

The drainage system for an urban area may be a separate system or may be a combined system where storm runoff and sewage flow through the same conduits. Fig.1.1 shows the storm water and waste water portion of the urban water resources system.

A simplified description of the major components of storm water disposal system is shown in Fig. 1.2. The figure is self explanatory. Rainfall is the cause of urban floods. It's interception by vegitation is negligible and the soil infiltration capacity is also usually minimum. Some of the precipitation which reaches roofs, pavements and various pervious surfaces, is trapped in the shallow depressions. After infiltration and depression storage have been abstracted, the residual precipitation flows overland in transit and is subjective to detention and storage effects. Overland flow from the flood is usually collected in street gutters or ditches which inturn are drained by street inlets. Flow from the ground surface enters the under ground system of conduits at street inlets and flow through the sewerage and/or drainage system. In a given instance either or both of the two components indicated by dashed lines (Fig.1.2) may be absent. Precipitation is input to the system and it falls over unsewered land along with outside flows. The flow over unsewered land is drained by drainage system along with interactions with ground water.

1.1.3 Urban drainage system(7,8)

The urban drainage system includes man made impervious pathways for guiding the flow of water over the

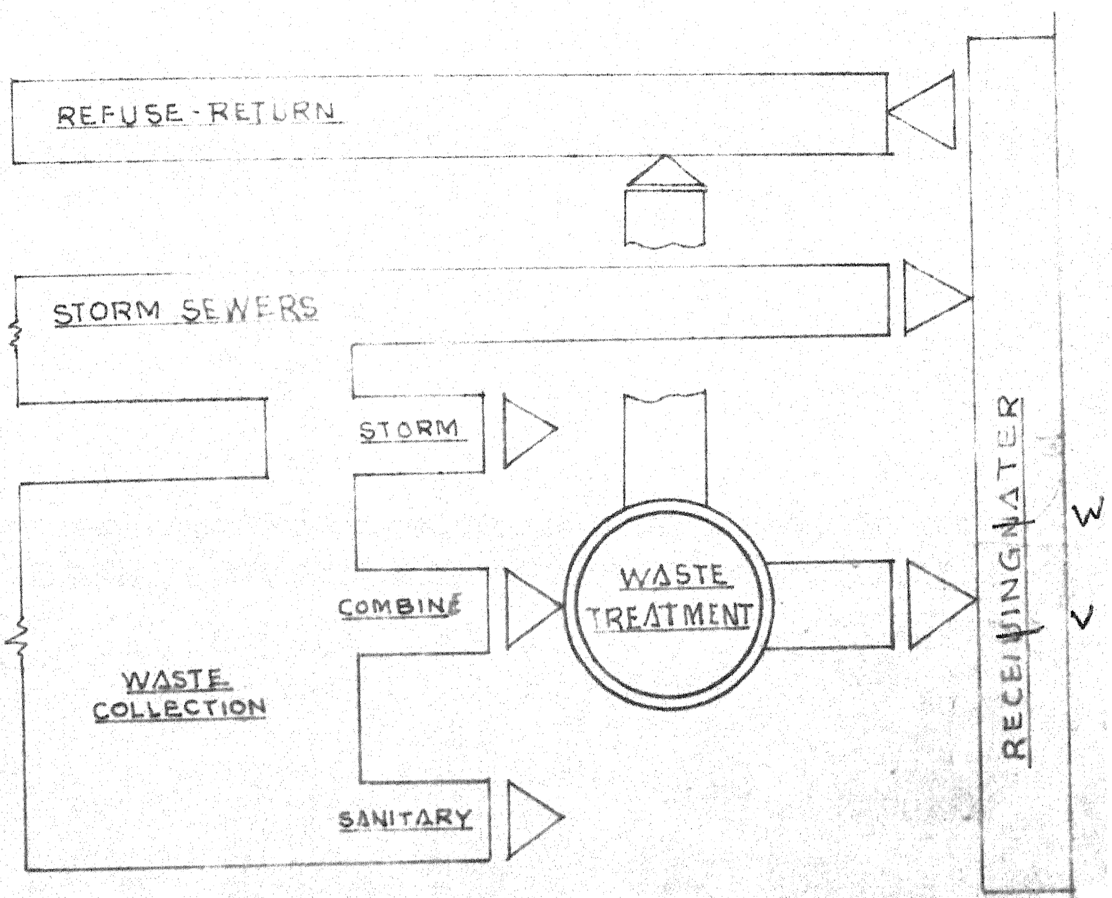


FIGURE - 1·1 : STORM WATER AND WASTEWATER PORTION OF URBAN WATER RECOURCES SYSTEM (B)

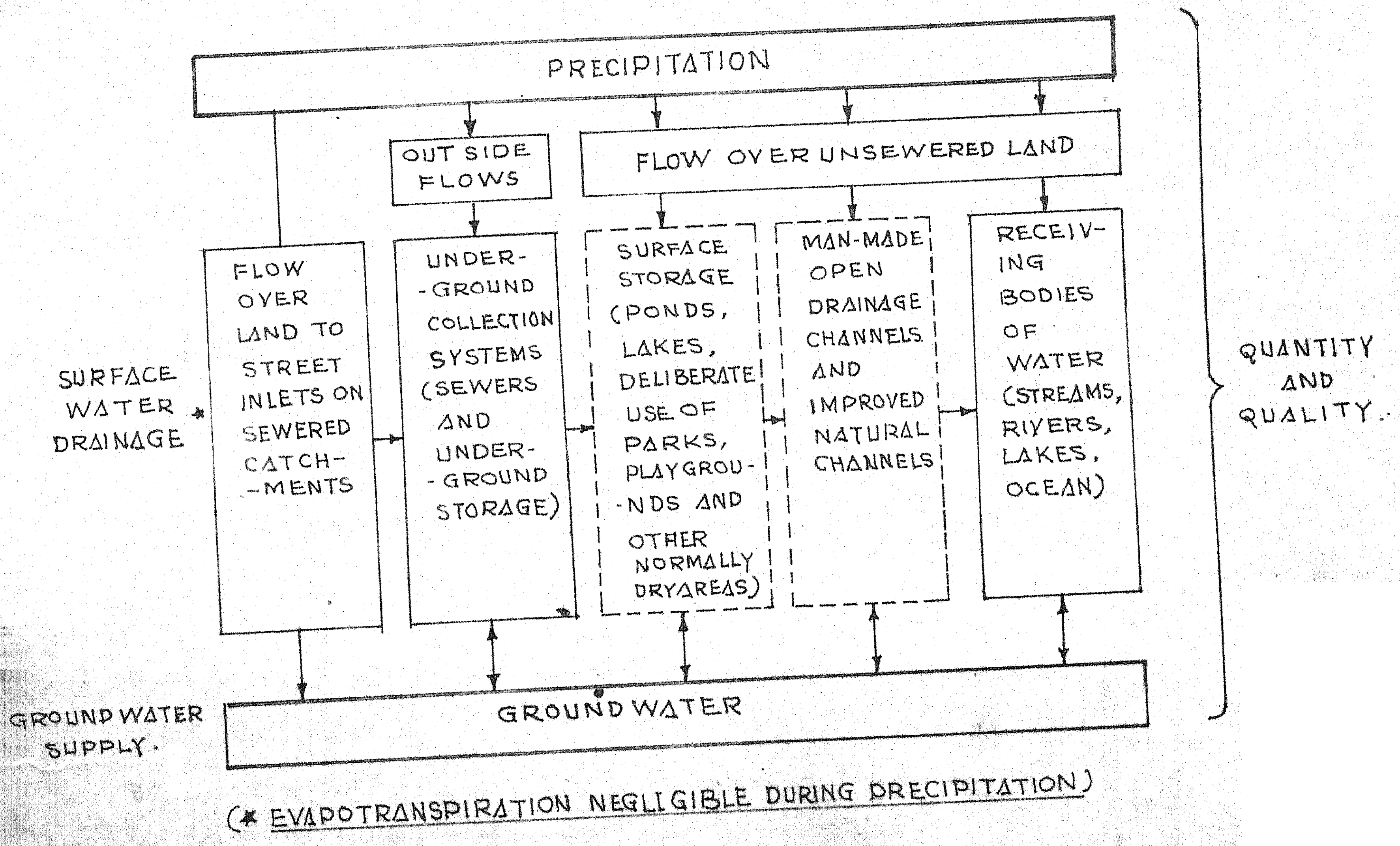


FIGURE_1·2: URBAN STORMWATER DISPOSAL PHYSICAL SUBSYSTEM (8)

ground surface (curbs, gutters, lined channels, paved parking areas, streets etc.) and below the ground (storm sewer, waste water sewers and combined sewers). The system also includes all appurtenances that guide, control and modify either the rate of flow or quality of runoff from urban drainage such as catch basins, storage basins, inlets, manholes, sediment traps, weirs and outfall structures.

Fig. 1.3 illustrates a simplified urban drainage system, which is considered to comprise of three subsystems, viz.; surface runoff subsystem, transport subsystem and the receiving water subsystem.

The Surface Runoff Subsystem is illustrated in Fig. 1.4. It depicts the drainage area tributary(dash line) draining into a drainage ditch which in turn leads to a sewer inlet. Each drainage subarea is characterized by it's area, a degree of imperviousness, it's slope , and certain coefficients that relate to its production of quality constituents that may be transported to the inlet by overland flow.

Input to the subsystem is comprised of rainfall that may be described in terms of an intensity-time graph

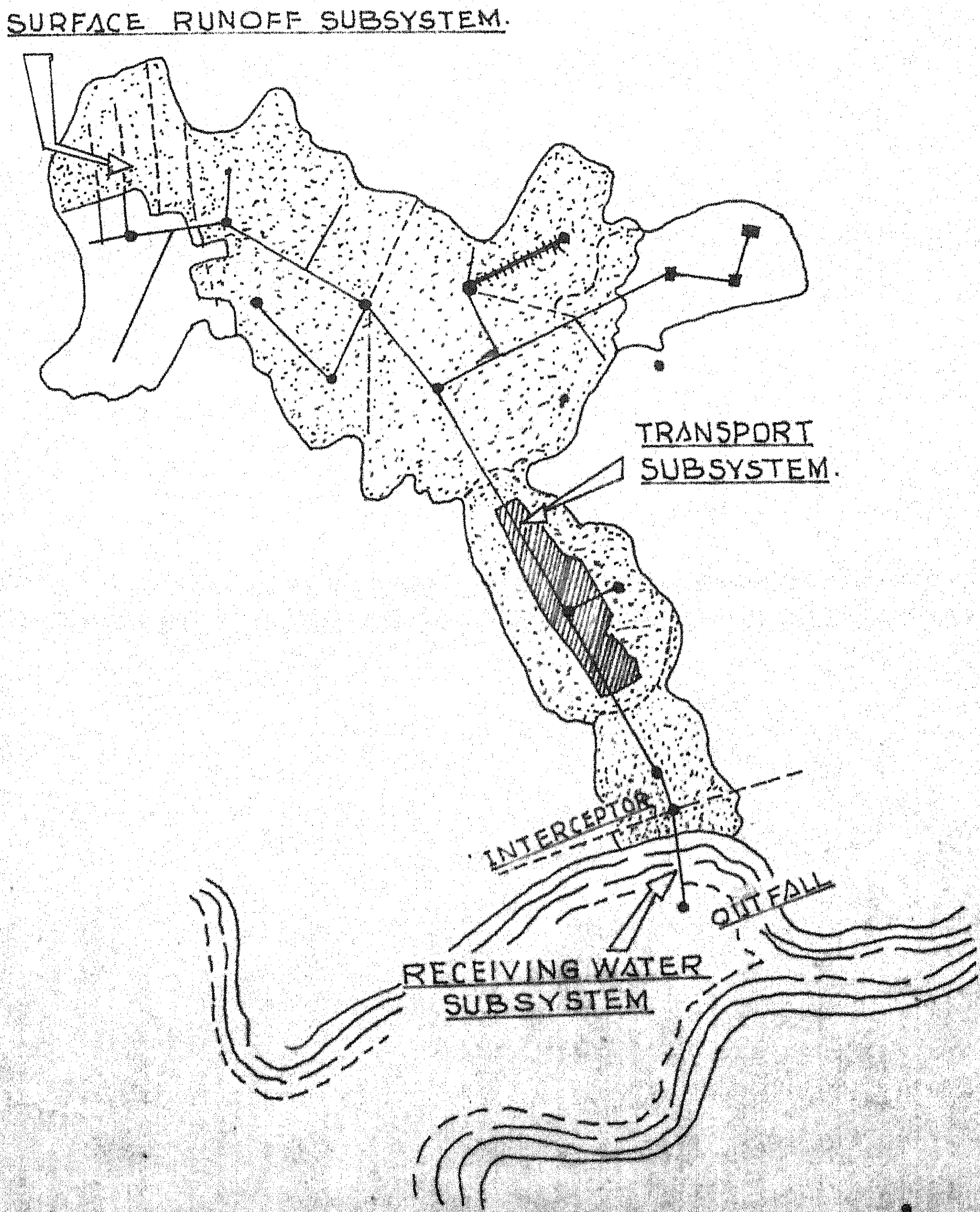


FIGURE. 1-3: - THE URBAN DRAINAGE SUB-SYSTEM (7)

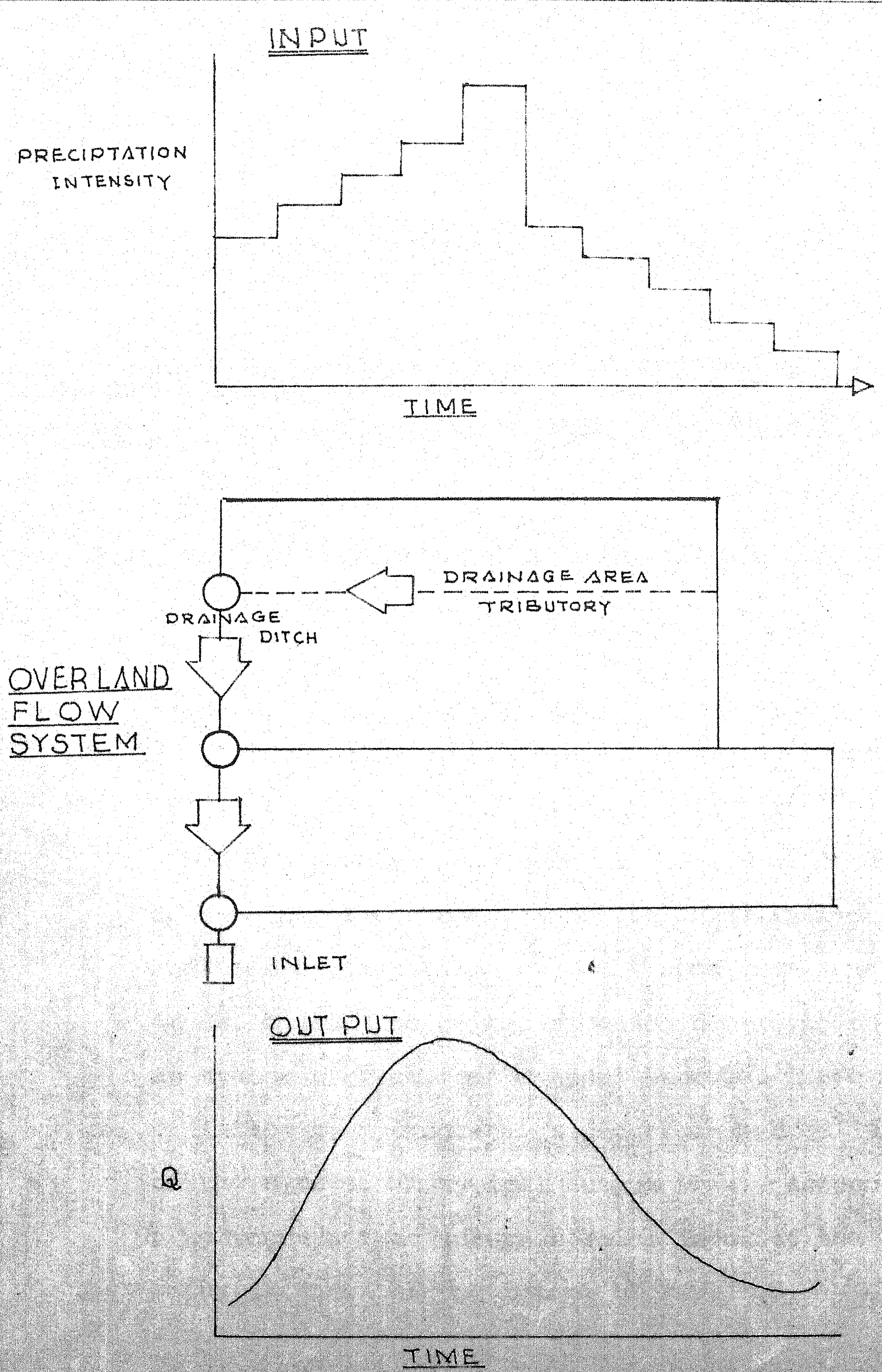


FIGURE_1-4 : SURFACE RUNOFF SUBSYSTEM

derived from direct measurements in the watershed. A typical rainfall hyetograph is shown on top of Fig. 1.4. The overland flow process modifies the rainfall hyetograph by infiltration, surface retention and transient storage, so that at inlet one observes a much modified inlet hydrograph, a temporal description of inlet flow (bottom of Fig. 1.4). The output of the Surface Runoff Subsystem is input to the Transport Subsystem.

Transport Subsystem (Fig. 1.5) comprises of physical works for conveying the storm waters and essential pollutant loads from all of the inlets in the drainage system through a network of underground conduits or open channels to a point of disposal. Enroute, flow in the system is modified by accretions to the system from other tributary areas, the degree of modification depending on such factors as system storage, off channel storage, phase relationships of inflow by hydrographs and certain hydraulic properties of the system. A typical output from Transport Subsystem, a hydrograph that inturn becomes input to the Receiving Water is shown at the bottom of Fig. 1.5.

The Receiving Water Subsystem may be a stream, a lake, an estuary or a coast. Discharge into an estuary is used for illustration in Fig. 1.6. The effect of discharge

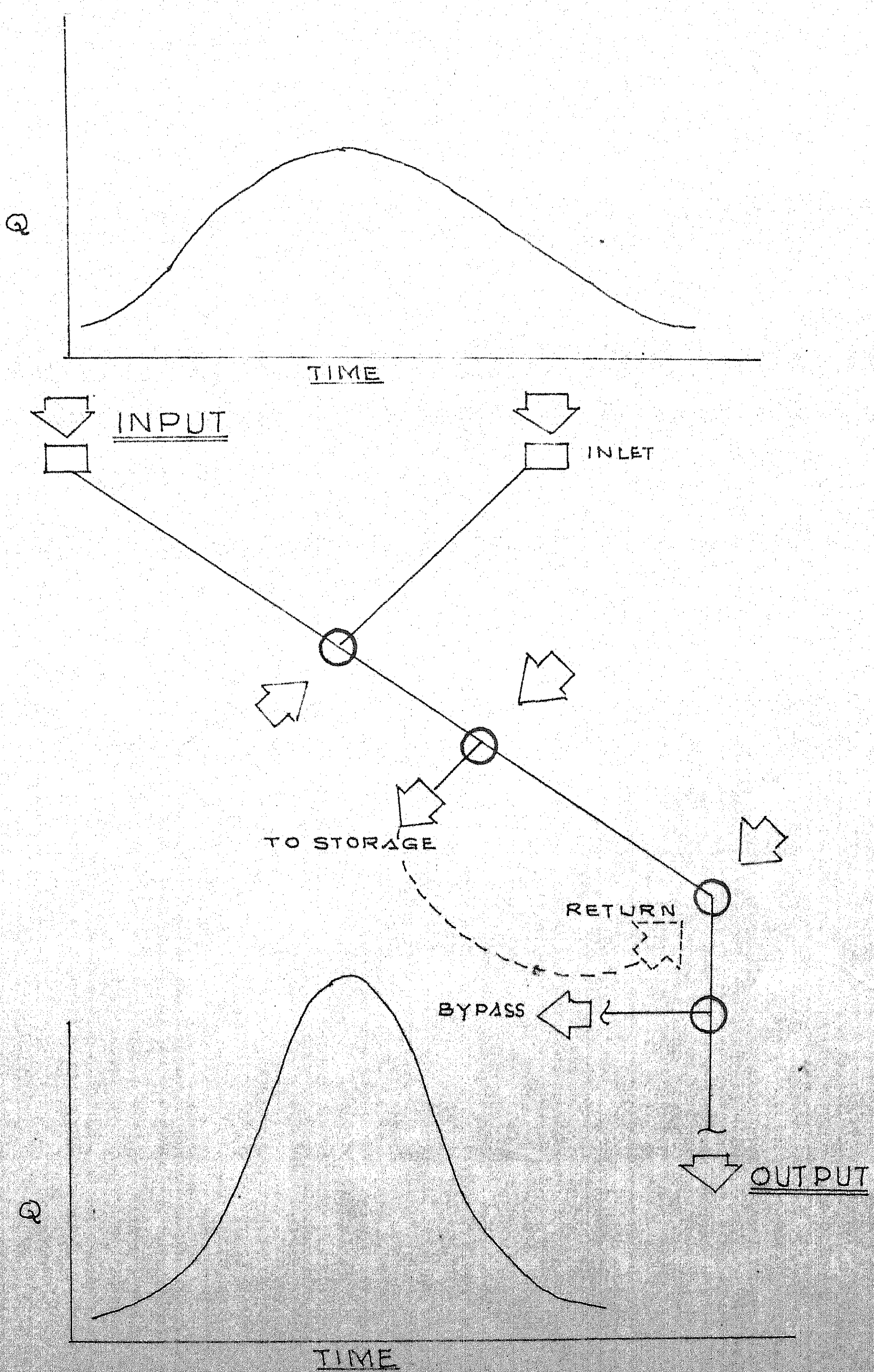


FIGURE_1-5: TRASPORT SUBSYSTEM

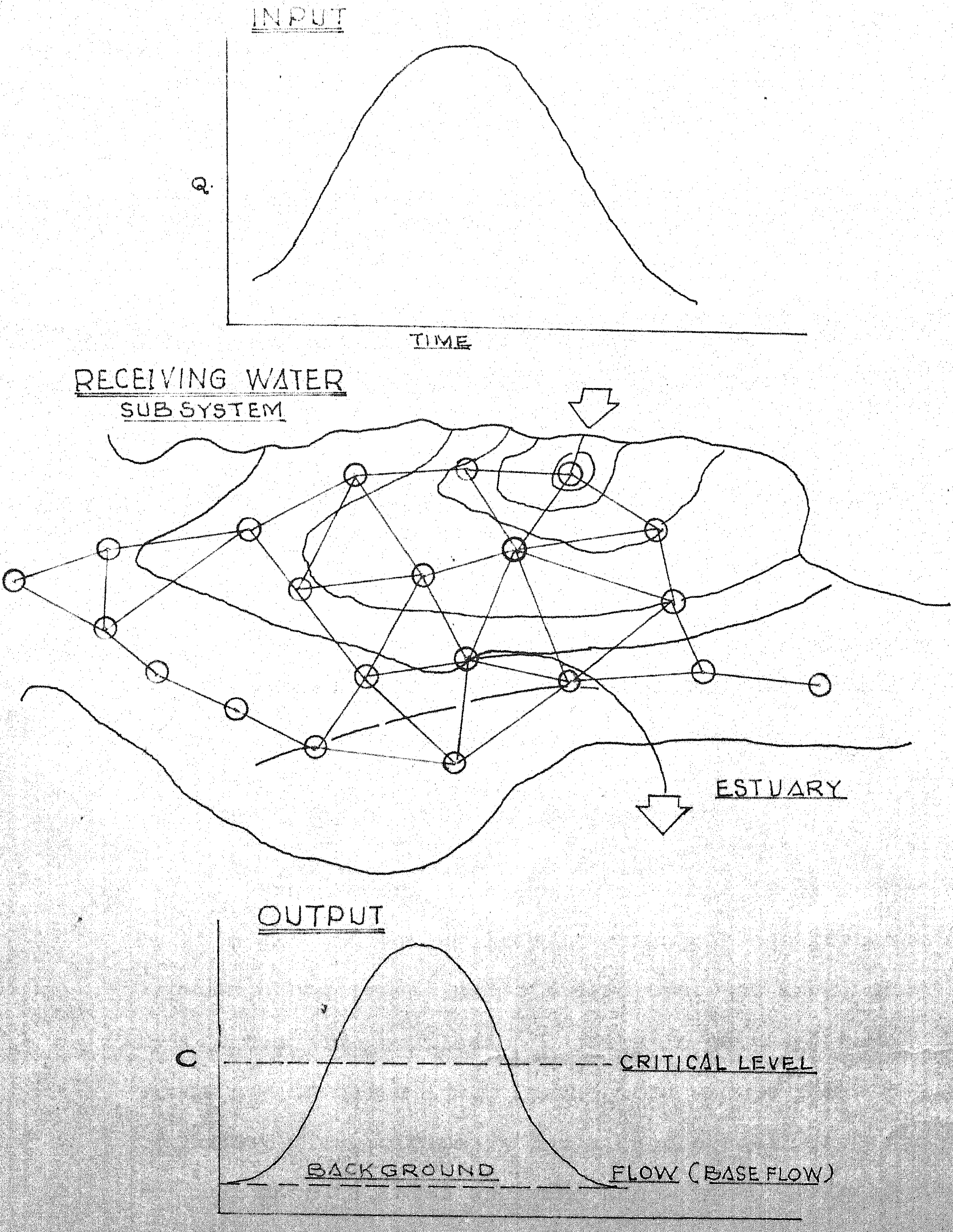


FIGURE_1-6: RECEIVING WATER SUBSYSTEM

on the Water Receiving Subsystem will probably be assessed in terms of the concentration of a particular quality constituent, it's distribution in space, the persistance in time and it's frequency of excedence of a certain critical level.

It may be noted that the characteristics of the outfall including it's location, type, level, and capacity very often affect the design of the urban drainage system. Hence it is very necessary to identify the drainage out-falls and their characteristics and their effects on the drainage system at the beginning of a study.

1.2 Modelling of Urban Drainage System

Urban hydrologic design in India is characterized by it's extreme variability in principle and practice (10). Because urban areas in India also overlaps rural green belt areas, the population density in parts of some urban areas may be quite low. Furthermore except perhaps in case of Bombay city, cities in India have a small proportion of builtup area to total area and hence urban drainage problems in India as in most other parts of developing world are quite different from these in the "concrete jungles" of the developed nations.

Because of complexities introduced by variable land use and hydrologic conditions, storm discharge from an urban watershed can best be analysed by dividing the total basin into smaller homogeneous units for which the individual runoff contribution can be computed. Collection of the individual subbasin outflows and their routing through main storm sewers permits the determination of the total watershed outflow at the basin outlet. Peak flow is the major consideration in sizing the conduits. Volume and hydrograph shape are critical for providing and sizing storage. Concentration and loading of pollutants are essential for evaluation of the capacity of receiving water to absorb them without harmfull effect and for sizing treatment facilities, if needed.

In India, the design of rural draines is often approached empirically; for example Delhi administration has improved the rural drainage system of Alipur Block for a discharge of 0.078 $m^3/sec/km^2$ and in Khanjawala Block for 0.056 $m^3/sec/km^2$. Discharge medium size drains (larger than 2,000 h.a.) from rural areas of the Najafgarh drain and Shahadara drain of Delhi and of North Bihar are estimated as 0.112 $m^3/sec/km^2$.

Rational Formula: Very often drainage systems are

designed in India by the use of rational formula, viz.;

$$Q = CIA/360 \qquad (1.1)$$

where Q = peak discharge in $m^3/sec.$,

I = intensity of rainfall in mm/hour for a critical duration estimated as the time of concentration for rural areas and the sum of inlet and routing times for sewered urban areas,

A = area of the basin in hectares, and

C = coefficient of runoff which depends on the nature of the surface.

The three factors affecting the design flow by the use of rational formula are respectively, the coefficient of runoff, the rainfall duration, and the frequency of design rainfall.

There is no uniformity in the estimation of these factors in India. Examples of current practices are indicated in reference (10). The limitations of rational method are well known. If the design is based on peak flow the "rational method is as good an arbitrary procedure as any considering the primitive state-of-the-art of urban hydrology". But complex storm water drainages which involve diversions from one catchment to another, flood storage, off channel storage, permanent storage, totally

impervious catchments, pumping installations, land use planning, and control of water quality including silting require knowledge of the flood hydrology rather than peak flow alone. Then the rational method is not applicable, and unit hydrographs and urban drainage simulation models are needed for rational and economic design of urban drainage systems.

1.2.1 Simulation models for urban catchment

Because of complexities in space time variable precipitation, nature of catchment areas and structure of drainage system, fairly complicated, urban drainage simulation models have been developed to study the complex process of urban runoff. These models involve the consideration of variation of storage and discharge characteristics of flow in different parts of system from one time element to the next using the principles of conservation of matter and energy. Several such models have been developed over the last decade and are available. Description and comparison of several such models are available from references. Table 1.2 shows a comparison of some major characteristics of some of these models. Even though these models are very complicated it seems necessary to adopt and use such models for large and complex urban drainage systems.

TABLE_1·2 : COMPARISON OF SOME MAJOR CHARACTERISTICS OF SOME MODELS

SR.No		CATCHMENT HYDROLOGY							SEWER HYDRAULICS								WATER QUALITY									MISCELLENEOUS				
		MULTIPLE CATCHMENT IN FLOWS.	DRY-WATER FLOW.	INPUT OF SEVERAL HYE TO GRAPHS.	SNOWMELT.	RUNOFF FROM IMPERVIOUS AREAS	RUN OFF FROM PERVIOUS AREAS.	WATER BALANCE BETWEEN STORMS.	FLOW ROUTINGS IN SEWERS.	UPSTREAMAND DOWN STREM CONT-ROL.	SURCHARGING AND PRESSURE FLOW.	DIVERSIONS	PUMPING STATIONS	STORAGE.	PRINTS STAGE.	PRINTS VELOCITIES.	DRY-WATHER QUALITY.	STORM WATER QUALITY.	QUALITY ROUTING.	SEDIMENTATION AND SCOUR.	QUALITY REACTIONS.	TREATMENT.	QUALITY BALANCE BETWEEN STORMS.	RECEIVING WATER FLOW SIMU-LATION.	RECEIVING WATER QUALITY SIMU-LATION.	CONTINUOUS SIMULATION.	CAN CHOOSE TIME INTERVAL.	DESIGN COMPUTATIONS.	REAL-TIME CONTROL.	COMPUTER PROGRAMME AVAI-LABLE
1	BRITISH ROAD RESEARCH LABORATORY.	●	●	●		●			●															●			●			●
2	ILLINOS URBAN DRAINAGE AREA SIMULATOR.	●				●	●		●					●	●	●											●	●		●
3	ENVIRNMENTAL PROTECTION AGENCY & VARIANTS.	●	●	●		●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●		●	●		●
4	UNIVERSITY OF CINCINNATI.	●				●	●		●															●			●			●
5	HYDROCOMP.	●	●	●	●	●	●	●	●	●		●		●	●	●	●	●	●		●		●	●	●	●	●		●	
6	MASSACHUSETTS INSTITUTE OF TECHNOLOGY.	●	●	●	●	●	●		●		●	●		●	●	●								●			●			
7	UNIVERSITY OF ILLINOIS.	●	●		●	●	●		●	●		●	●	●	●	●											●	●		●
8	BATTELLE NORTH WEST	●	●	●		●	●		●		●	●		●	●	●	●	●	●			●					●	●	●	●
9	CHICAGO FLOW SIMULATION	●	●	●	●	●	●	●	●					●	●									●		●	●			●
10	CHICAGO HYDROGAPH METHOD	●	●	●		●	●	●	●															●			●	●		●
11	CORPS OF ENGINEERS (STORM)				●	●	●	●				●		●				●					●			●				●

1.3 Statement of the Problem

Urban hydrologic design in India is based on rational method. Because of its limitations, particularly where storage and pumping are available it is necessary to use more realistic design models for urban drainage. These may result in considerable saving in construction and operation of the urban drainage system in India. It is proposed to implement a suitable computer simulation model for design of urban drainage system in India and use it to analyse and evaluate some existing systems.

1.4 Objective of the Study

The major objective of the study is to implement one or more simulation models in the IBM 7044-1401 computer system at Indian Institute of Technology Kanpur; validate it with test data if available, and to use it for analysis and design of some urban drainage systems in India.

1.5 Scope of the Study

Because of limitations in the availability of computer programme, in the capacity of digital computer system, in the availability of field data for real system, and time for study, the scope of the study is limited to the following:

i) The study is limited to the use of ILLUDAS; The Illinois Urban Drainage Area Simulator developed by Michael L. Terstriep and John B. Stall of the Illinois State Water Survey;

ii) Only four urban catchments are used for the study;

iii) Whereever appropriate data were not available reasonable assumptions were made; and

iv) The storm durations and frequencies were generally limited to 30 , 45 , and 60 minutes and 2 , 5 , and 10 years respectively.

1.6 Significance of the Study

Analysis and design of urban hydrologic system in India are essentially emperical in nature. Because of increasing urbanization , it seems necessary and possible to use simulation models for urban catchment. It is possible to evaluate the risk involved in empirical designs and also achieve economy in design by taking into condideration the storage characteristics of the system by using simulation model.

Very few simulation models have been tested for Indian Watersheds. This study will hopefully lead to a better understanding of the hydrology of flow in urban drainage systems and better design of such systems.

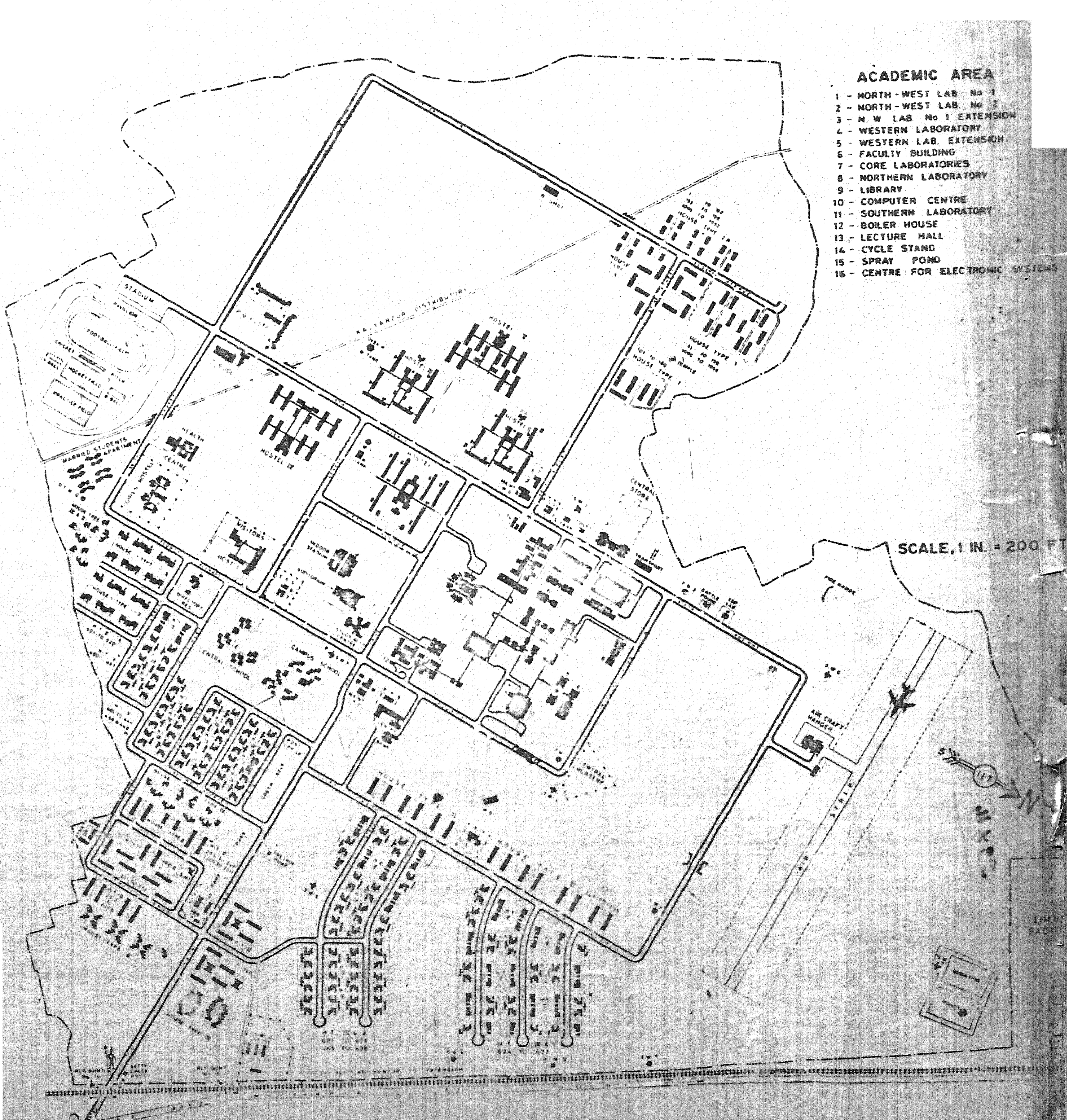


Fig.3·1 Campus plan of Indian Institute of Technology Ka

1.7 Organization of the Study

The study is reported in the following sequence:

i) Introduction, description, and implementation of ILLUDAS; Illinois Urban Drainage Area Simulation (Chapter 2);

ii) Analysis of drainage subsystems at Indian Institute of Technology Kanpur (Chapter 3);

iii) Analysis of drainage subsystems in three cities of Punjab, viz.; Amritsar, Jullendhar and Ludhiana (Chapter 4); and

iv) Summary, conclusions and suggestions for future study (Chapter 5).

2. MODEL SELECTION AND IMPLEMENTATION

2.1 Model Selection

There are several simulation models for urban drianage systems. A comparison of the capabilities of models, the limitations of data availability, lack of interest in quality simulation and simplicity of the model indicated that ILLUDAS (Illinois Urban Drainage Area Simulator) model developed by the Illinois State Water Survey may be suitable for purposes of this study. The computer programme, user's manual, and test data were available for the study.

2.2 Description of ILLUDAS

British Road Research Laboratory developed and used successfully in U.K. a RRL method for analysis of urban drainage systems (11). Terstriep and Stall (12) tested the model and improved it resulting in the development of the model ILLUDAS.

ILLUDAS uses an observed or specific rainfall pattern as the primary input. The basin is divided into sub-basins one for each design point in the basin. Paved areas and grassed areas are accounted for separately and

the hydrographs produced from each sub-basin from the respective contributing areas are determined. These hydrographs are combined and routed down stream from one design point to the next untill the outlet is reached. It is possible to determine pipe size at each design point and the detention storage as part of the design problem. Some of the salient features of ILLUDAS model are described below.

2.2.1 Paved area hydrograph

ILLUDAS utilizes the directly connected paved area concept of the RRL method. Equal time increments of rainfall are applied to the directly connected paved area in a small sub-basin of total urban basin. The travel time required for each increment of runoff to reach the inlet at the down stream end of sub-basin is computed. This results in a surface runoff hydrograph for each sub-basin. These surface hydrographs are accumulated in a down stream order through the basin. The accumulated inflow is routed through each section of the pipe to account for the temporary storage within the pipe. Thus outflow hydrograph at each important section of the system, and at the outlet of basin are determined.

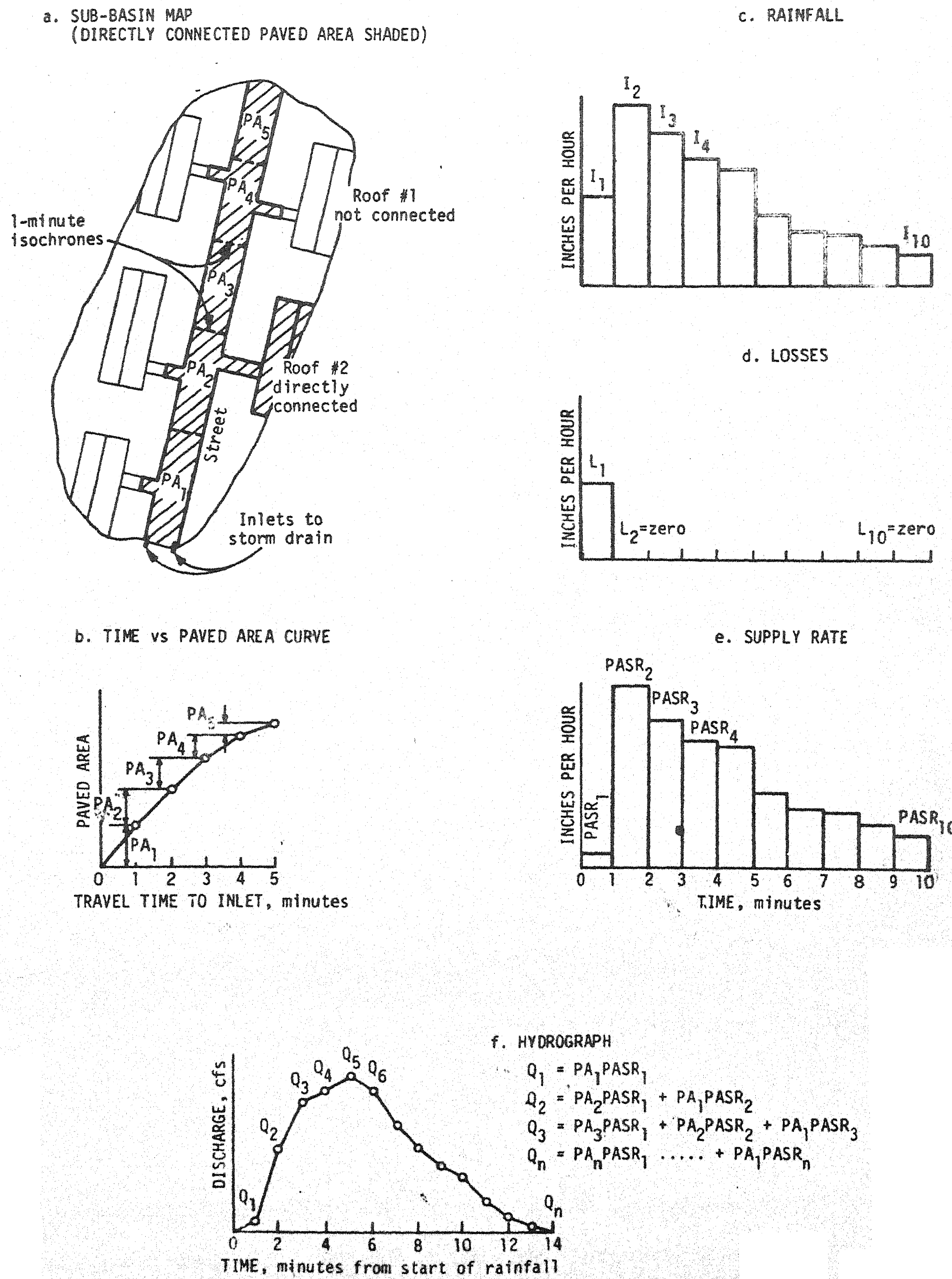


Figure 2.1 Elements in the development of the paved-area hydrograph

The input is a rainfall pattern as a series of intensities of equal duration (Fig. 2.1 c) which can be an actual event or a design storm. For paved areas the losses consist of initial wetting and depression storage. They are combined and treated as initial loss to be subtracted from the rainfall pattern (Fig. 2.1 d) . After subtracting these losses from rainfall pattern, the remainder of rainfall referred as paved area supply rate (PASR) will appear as runoff from the paved area.

The basin is divided into a number of sub-basins each of which is normally a homogeneous portion of the basin tributary to one or more inlets that constitute a design point in the drainage network. The paved area is directly connected to the storm drainage system (Fig.2.1 a) and the travel time from farthest point on the paved area to the design point are determined. Thus the time of travel for the runoff from various parts of paved area to the inlet at down stream end of the sub-basin may be determined.

The time area curve is assumed to be a straight line from the farthest point to the outlet. It is described at intervals of t which are equal to time interval for the rainfall pattern. In general this time interval, Δt, which is used through out the computation, should be as short as

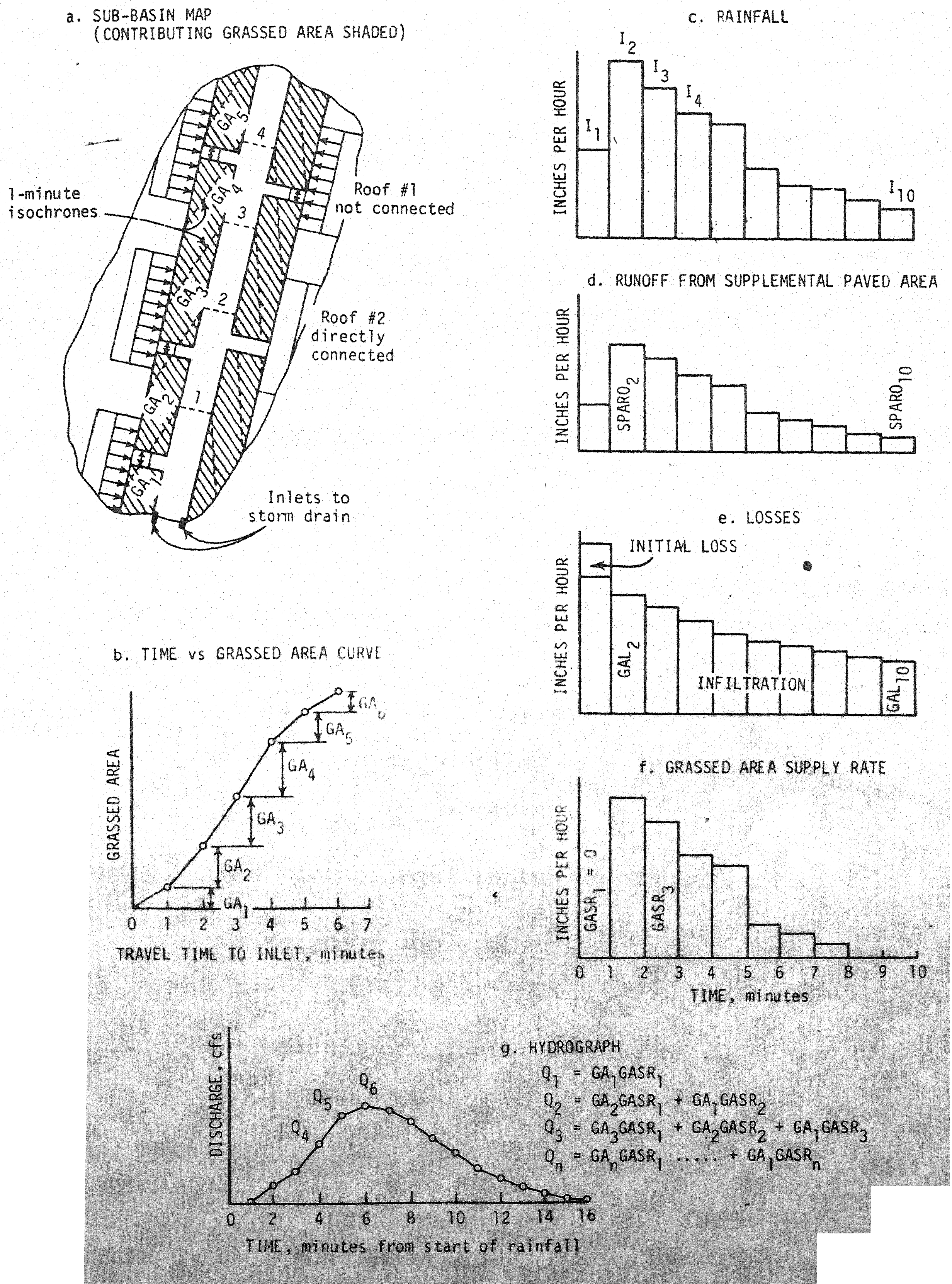


Figure 22 Elements in the development of the grassed-area hydrograph

obtained by subtracting these losses from the sum of rainfall plus SPARO. The grassed area which contributes to the immediate runoff to the storm is determined and the time of equilibrium which represents essentially time of travel from the farthest point on the contributing grassed area to the outlet is determined by using the following equation by Izzard (1946);

$$qe = 0.0000231\ IL$$

where, qe = Discharge of overland flow, in cfs per foot of width, at equilibrium.

I = Supply rate in inches per hour assumed to be 1.0 in this study,and

L = Length of overland flow in feet,

$$te = 0.033\ kL\ qe^{-0.67}$$

where, te = time of equilibrium in minutes.

$$K = (0.0007I + C)\ S^{-0.33}$$

where, S = Surface area in feet per foot,and

C = Coefficient having a value of 0.046 for blue grass turf.

Since the equilibrium condition is reached asymptotically, Izzard (1946) arbitrarily determined by these equations was found to be in close agreement with empirical equations for time of concentration developed by Hieks (1944).

As in the case of paved area runoff, in the case of grassed area runoff also the time vs cummulative area curve was assumed to be a straight line (Fig. 2.2b). The ordinates of grassed area hydrograph (Fig. 2.2g) are computed for each sub-basin by convolving the grassed area supply rate to the time vs supply rate curve. There are inturn combined with corresponding paved area hydrographs. These combined hydrographs constitute the surface hydrograph for each sub-basin and are point input into the drainage network. Whereever the sub-basin is at upper most reach of any subsystem , the surface hydrograph is entered into the system by routing it through the reach to the next input point down stream. If the sub-basin occurs along a drainage line but not at it upstream end , then its surface hydrpgraph is combined with the upstream hydrpgraph and the resulting combined hydrograph is routed down stream to the next input point. If the sub-basin is located at the confluence of two conduits, the surface hydrograph of the sub-basin is combined with the coverging hydrograph before routing it down stream to the next input point.

2.2.3 Infiltration

In an urban basin infiltration occurs through grassed area in addition to initial losses due to depression storage.

It is assumed that depression storage is to be satisfied before any infiltration takes place and a normal value of 0.2 inches is adopted for depression storage even though this can be varied in the programme. Initial losses are estimated by the Horton's equation;

$$f = f_c + (f_o - f_c)\, e^{-kt}$$

where, f_o = Initial infiltration rate, in inches,

e = Base of natural logarithm,

k = A shape factor selected as 2, and

t = Time from start of rainfall.

The values of f_o and f_c are used for different type of soil are given in Table 2.1. This equation is solved by ILLUDAS by Newton-Raphson technique and is used for estimation of grassed area supply rate.

2.2.4 Routing procedure

The combined hydrograph for each sub-basin from the paved and grassed area is the point input into the drainage network. A simple storage routing technique is used to route this hydrograph through any section of drainage conduit. Assuming uniform flow and using Manning's equation a determinate storage discharge relationship is derived for each reach, since the length and geometry of the reach are known. Consideration of circular, trapezoidal, and

TABLE 2.1 : FACTORS USED FOR CALCULATING THE STANDARD INFILTRATION CURVES (12).

Item	Value			
	1	2	3	4
Hydrologic soil group				
USDA designation	A	B	C	D
ILLUDAS designation	1	2	3	4
Final constant infiltration rate, f_c, inches per hour	1.0	0.50	0.25	0.10
Initial infiltration rate, f_o, inches per hour	10.0	8.00	5.00	3.00
Depression storage, inches	0.20	0.20	0.20	0.20

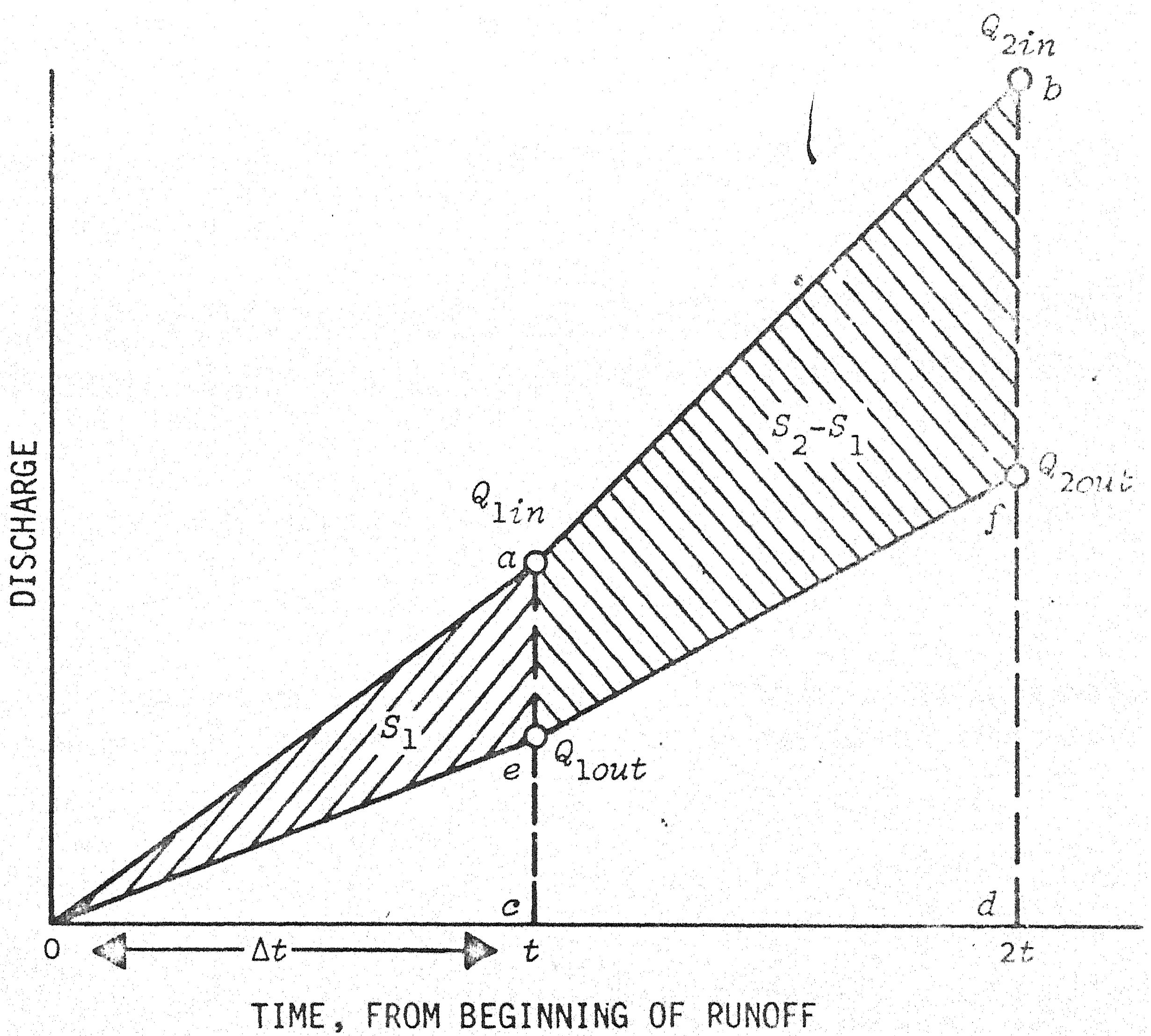


Fig. 2 3 Elements in Storage Routing Technque

rectangular sections are possible in ILLUDAS. Using short time increment and reach lengths, errors due to uniform flow assumptions are minimised.

The elements in the storage routing technique are indicated in Fig. 2.3 . The line $OQ_{1in}\ Q_{2in}$ is a section of the inflow hydrograph at the upper reach and the line $OQ_{1out}\ Q_{2out}$ is a section of outflow hydrograph at the lower end of the reach at times t and 2 t respectively from the beginning of runoff. Let S_1 and S_2 be the total storage in the reach at times t and 2t. At any time t the values of Q_{1in}, Q_{2in}, Q_{1out} and S_1 are known. From continuity equation it is known that;

$$t/2\ (Q_{1in} + Q_{2in} - Q_{1out}) + S_1 = S_2 + t/2\ Q_{2out}$$

Since the left side of the equation is known, the right side may be solved for Q_{2out} from the storage discharge relationship for the reach. By this step-by-step procedure, all ordinates of routed down stream hydrograph may be determined.

2.2.5 Flood water detention basins

During floods, temporary storage of flood water may be provide by either artificial man-made detention basins or by permitting temporary flooding along drainageways

through greenbelt areas. ILLUDAS provides for incorporation of specified volumes of detention storage allowable at any point in the basin. It will also report the volume of detention storage accumulated during the passage of the design storm.

2.3 Details of Programme

2.3.1 Flow chart

The flow chart for ILLUDAS is indicated in Fig.2.4. The steps follow the details of the earlier sections and so they are not repeated here.

2.3.2 Computer programme

The computer programme for ILLUDAS was developed by Terstriep and Stall of Illinois State Water Survey and were made available for the study by Mr. Stall. It is written in Fortan IV language and consists of around 700 cards and requires a memory of 24 K words. It is implemented in the IBM 7044-1401 digital computer system of Indian Institute of Technology, Kanpur.

2.3.3 Input data

Fig. 2.5 shows a complete input deck in its proper sequence and the code sheet used for ILLUDAS input data is

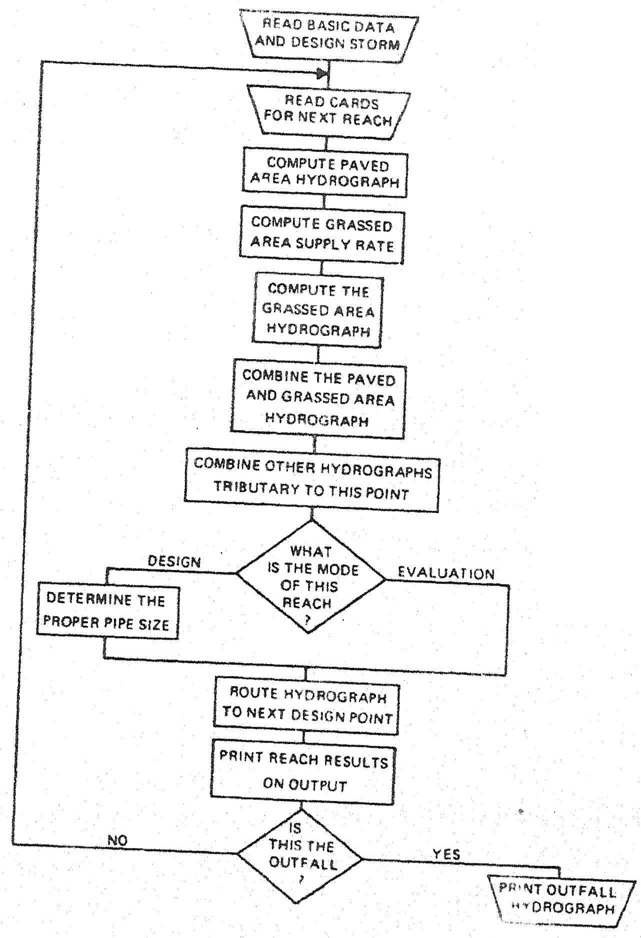


Figure 2•4 Flow chart for ILLUDAS

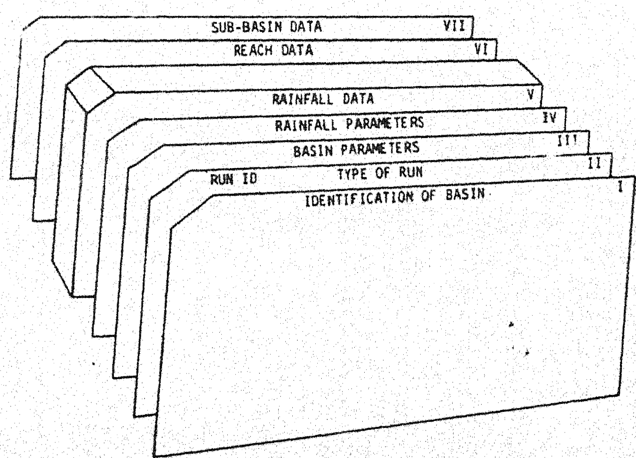


Figure 2•5 ILLUDAS data deck sequence

CARD NUMBER

I

IDENTIFICATION OF BASIN
20 A4

II

1	2	3
RUN NUMBER	NEW DESIGN	EVALUATION
F10.0	F10.0	F10.0

III

1	2	3	4	5	6
BASIN AREA	PAVED ABSTRT	GRASSED ABSTRT	SOIL GROUP	MINIMUM DIAMETER	NEW PIPE "n"
F10.0	F10.0	F10.0	I10	F10.0	F10.0

IV

1	2		4	5	6	7	8
RAINFALL PROVIDED	NO. OF INCREMENTS	Δt	STANDARD DISTRIBUTION	DURATION	RETURN PERIOD	TOTAL RAIN	AMC
F10.0	F10.0	F10.0	F10.0	F10.0	F10.0	F10.0	F10.0

V

RAINFALL DATA (OPTIONAL)
10F8.0

VI

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
BR	RCH	TERM BR	CON BR	OPTION	L	S	"n"	SEC	DIAM	H	W	LS	QM	RATIO	STORE	END	HYD
F3.0	F3.0	F3.0	F3.0	I3	F5.0	F5.0	F5.0	I1	F4.0	F5.0	F5.0	F5.0	F5.0	F5.0	F5.0	A3	I2

VII

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
BR	RCH	AREA	DCPA	% DCPA	SPA	% SPA	PVD ENT	PVD L	PVD S.	GA	% GA	GA ENT	GA L	GA S	SOIL
F3.0	F3.0	F9.0	F5.0	F3.0	F5.0	F3.0	F5.0	F5.0	F5.0	F5.0	F3.0	F5.0	F5.0	F5.0	I2

Figure 2-6. Code worksheet used for ILLUDAS input data

indicated in Fig. 2.6. The following discussion of the required input data follows item by item the same order as the input deck.

Card 1, 2:- Indentification. Column 2 to 70 of identification cards are used for any alpha numeric information by the user and it will be printed on the first two lines of the output to serve as identification.

Card 3:- Type of run. This contains run number which is a numeric information to identify the particular set of data; new design and evaluation, which should be a positive integer and a blank for a new design or when the proper pipe sizes for all reaches in the basin are desired or should be a blank and a positive integer if the pipe sizes are all known and analysis is desired.

Card 4:- Basin Parameters. This contains the basin area in acres; paved area abstraction, which is the initial abstraction from paved areas and this should be 0.1 inch unless the user has a better estimate; grassed area abstraction which is the initial abstraction for grassed areas and should normally be 0.2 inch; predominant soil group which defines the U.S. Soil Conservation Service Classification the most common hydrologic soil group in the watershed denoted by numbers 1, 2, 3 and 4 corresponding to hydrologic soil groups A, B, C, and D recepctively; minimum diameter in inches

to be used in design with increments of 3 inches; and Manning's roughness coefficient 'n' to be assigned to a new pipe with generally 0.013 for concrete pipes and 0.015 for clay pipes.

Card 5:- Rainfall parameters. This includes rainfall provided indicated by a positive integer that rainfall increments are provided by the analyst in which case only item 1,2,3 and 8 of this card need be completed; number of rainfall increments which should be left blank if the standard distribution (Table 2.2) is used; time increments in minutes, which will be generally 1/2 to 1/3 of the average inlet time at which rainfall increments are specified; land use; standard distribution with a positive integer indicating that the standard rainfall distribution provided in ILLUDAS will be used in which case items 3,5,6,7 and 8 of this card must also be specified, duration which is generally 60 minutes for urban drainages while larger or smaller durations may also be used; return period which is the recurrence interval for the design storm; total rainfall in inches is the design storm obtained generally from the India Metroelogical Department for the respective duration and frequency and antecedent moisture content defined by a number 1,2,3 or 4 to define the degree of wetness of the basin.(subsection 2.2.3).

TABLE 2.2: STANDARD TIME DISTRIBUTION OF STORM RAINFALL(12).

Sl.No.	Cummulative storm time		Cummulative storm rainfall percent
	minutes	percent	
1	5	8.3	21
2	10	16.7	44
3	15	25.0	59
4	20	33.3	68
5	25	41.7	75
6	30	50.0	80
7	35	58.3	84
8	40	66.7	87
9	45	75.0	90
10	50	83.3	94
11	55	91.7	97
12	60	100.0	100

Card 6:- Rainfall data. The rainfall pattern upto 500 rainfall increments and at the rate of 10 per card with the first rainfall increment as zero are given. These data are used only when there is a positive integer in item 1 of card 5.

Card 7:- Reach data. This card includes branch number which reffers to each length of channel or pipe; reach number which is the identification number for each length channel within a branch with an upper most length numbered zero and number of each consecutive down stream reach is a particular branch increased by one; terminating branch and continuing branch which are the only items in the confluence card to indicate the confluence of two branches with the number of branch that terminates the confluence and the number of branch that continues through the confluence respectively (the confluence card is not used until all reaches upstream of the confluence have been completed); option to define the mode to be used for this reach with 1 indicating new design, 2 analysis and blank returning control for general mode indicated in card 3; reach length in feet; slope in percent; Manning's n for an existing system; section with 1, 2 or 3 indicating that existing corss section of the reach is circular, rectangular, or trapezoidal respectively and a blank for a new system;

diameter in inches of the existing section; height in feet for rectangular and trapezoidal section; bottom width in feet of rectangular or trapezoidal section; lateral slope (side slope) of the trapezoidal section in rise per unit horizontal length; maximum allowable discharge if any for the section in cusec; rainfall ratio which is the ratio of actual rainfall in the sub-basin to the total rainfall specified in card 5; allowable storage for detention in 1000 cft, if any, existing or to be provided;end test defined by the word END for the last reach of the basin; print hydrograph with a positive integer indicating that the ordinates of the design hydrograph entering the reach be printed in tabular form as part of the out.

Card 8:- Sub-basin data. Which is continuation of card 7 with branch and reach as in card 7 for identification; sub-basin area in acres; directly connected paved area in acres; percent directly connected paved area in lieu of previous item and otherwise blank; supplemental paved area in acres; percent supplemental paved area in lieu of previous item and otherwise a blank; pawed area entry time in minutes if given by the user as also blank; paved area flow path defining the length in feet of largest probable flow path; paved area slope in percent along the flow path with blanks in this and earlier item if paved area entry time is specified earlier;

contributing grassed area in acres; percent contributing grassed area in lieu of the previous item and otherwise blank; grassed area entry time in minutes or a blank if the next two items are specified; grassed area flow path in feet; grassed flow path slope in percent; and hydrologic soil group when the soil in that particular sub-basin differs from the predominent soil shown on card 3. Card 7 and 8 are repeated for each of the reaches .

2.3.4 Output

Output format depends upon whether the results are from the analysis of the existing system or for a new design. For a new design, output consists of the following:

Identification from card 1 and 2 of input data; input data for the basin and the rainfall; tabular data for each branch-reach combination including the required pipe diameter and capacity and the ordinates of the outlet hydrographs in cusecs.

The output for an analysis of the drainage system consists of the following:

The identification as given in card 1 and 2 of input data; basin and rainfall characteristics; the results in a tabular form for each branch and reach combination and

the hydrograph at the outlet. It may be noted that in a problem with part of system existing and other part to be designed the output will be a combination of the sequences given above.

2.4 Implementation and Validation

The computer programme for ILLUDAS developed by Terstriep and Stall was available for the study. It is implemented in the IBM 7044-1401 digital computer at Indian Institute of Technology, Kanpur with some modifications to suit the requirements of the operating system.

Test data for a sample basin are given in reference(12) for testing and validating computer programme. They were used and the results for a new design as well as for evaluation for a existing drainage system for sample basin agreed with results given in reference. Thus the computer programme for ILLUDAS was validated and it is available for use in subsequent phases of the study.

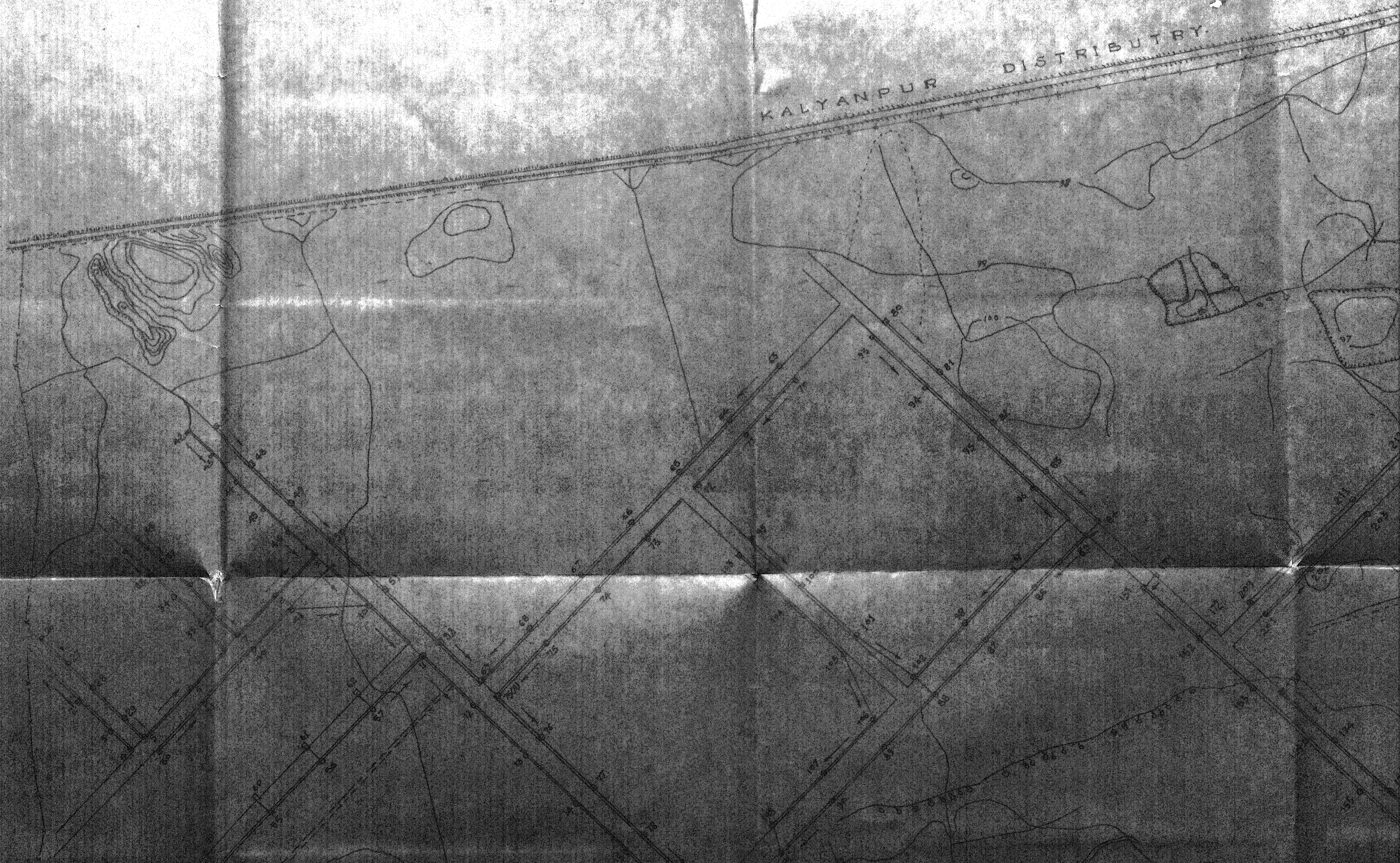
3. DRAINAGE SYSTEM AT INDIAN INSTITUTE OF TECHNOLOGY KANPUR

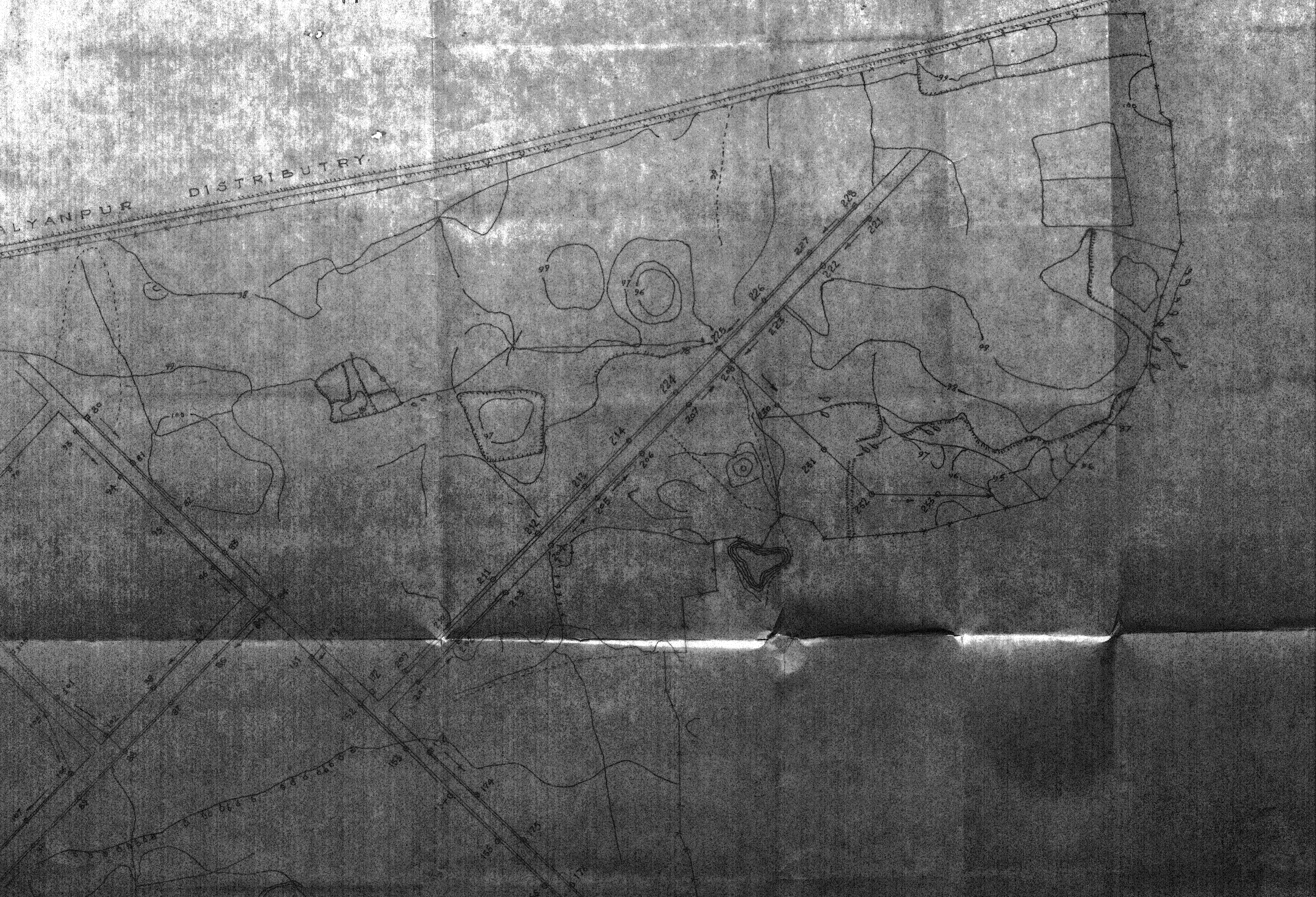
3.1 Introduction

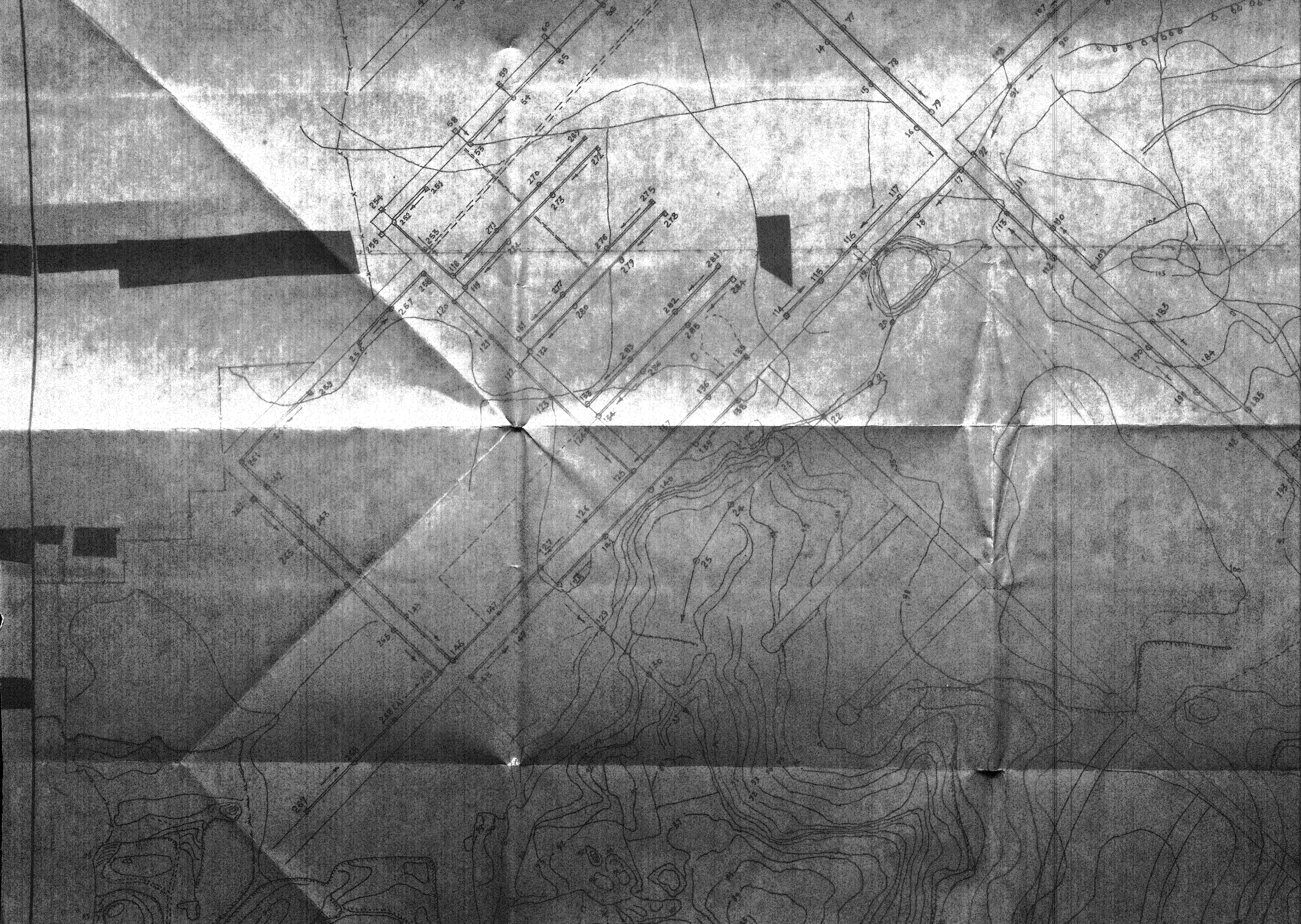
I.I.T. Kanpur is located in Uttar Pradesh, 10 Kms west of Kanpur on the Grand Trunk Road towards Delhi. What was agricultural fields was developed since 1962 into an educational campus that has been planned and land scaped for environmental freedom. It consists of a central cluster of buildings that have educational, administrative and research facilities and is surrounded by student's halls of residence, faculty and staff quarters and community service buildings. There is also an air strip and an oxidation pond for sewage treatment. It is proposed to consider the design for drainage of the I.I.T. Kanpur campus and compare them if possible with the actual drainage system provided.

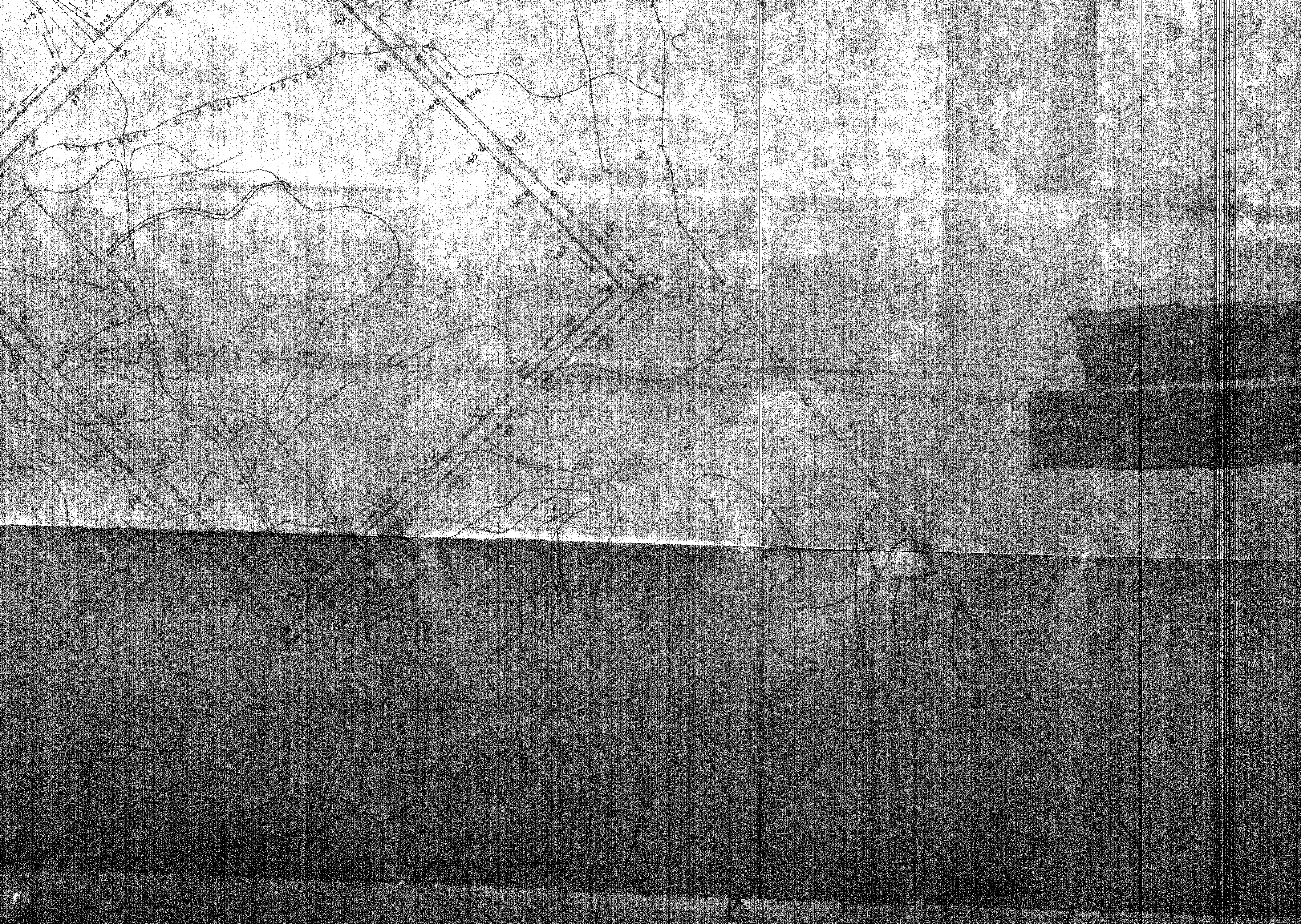
3.2 Description of the System

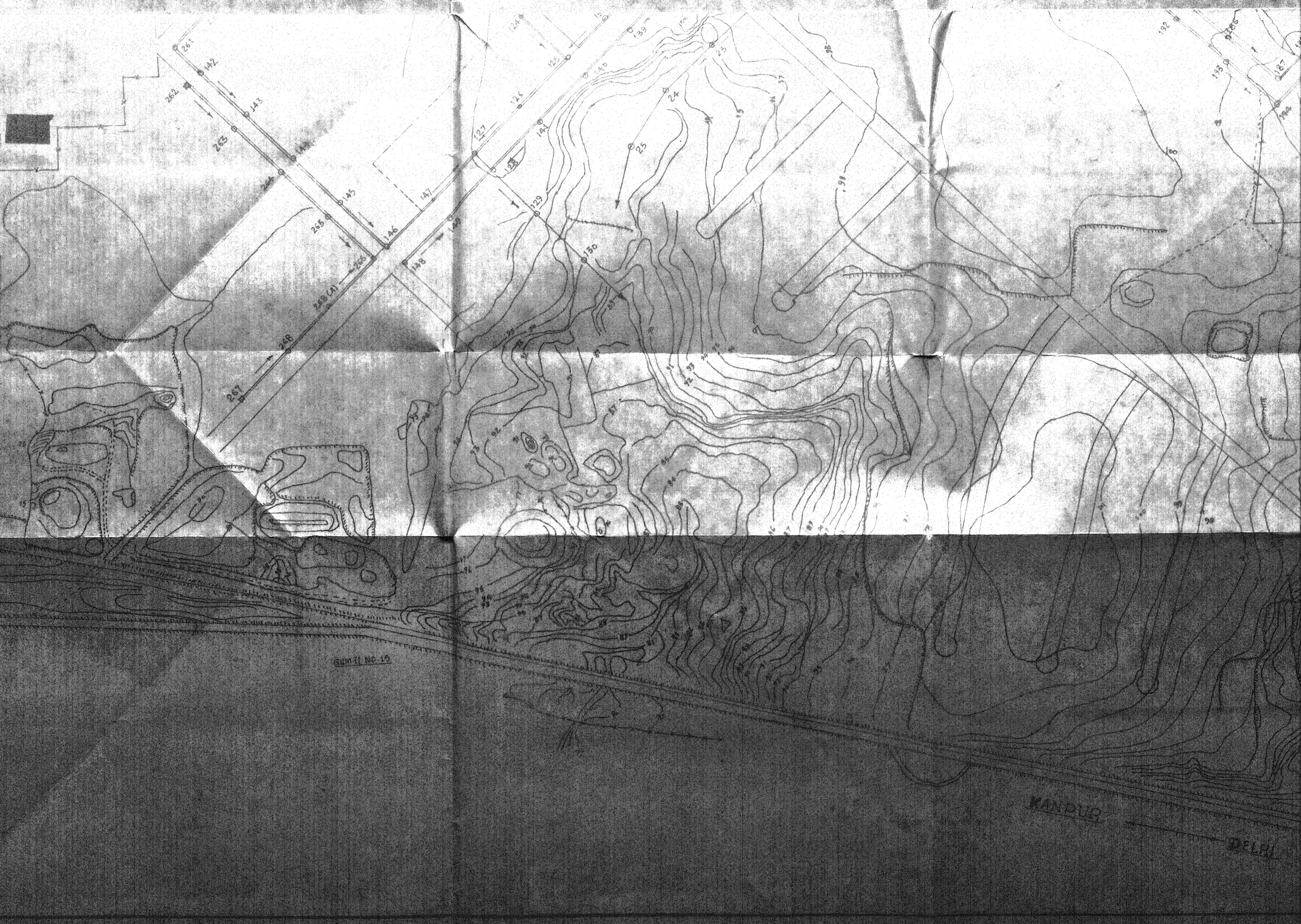
The campus plan of I.I.T. Kanpur is shown in Fig. 3.1. There is a east west main drive for access from G.T. Road and there are a number of avenues at right angles to the main street. The storm water drainage system for I.I.T. Kanpur campus along with the inlets, the direction of flow and the outlets are indicated in Fig. 3.2 along the contour levels over the campus area. I.I.T. Kanpur is situated


KALYANPUR DISTRIBUTRY

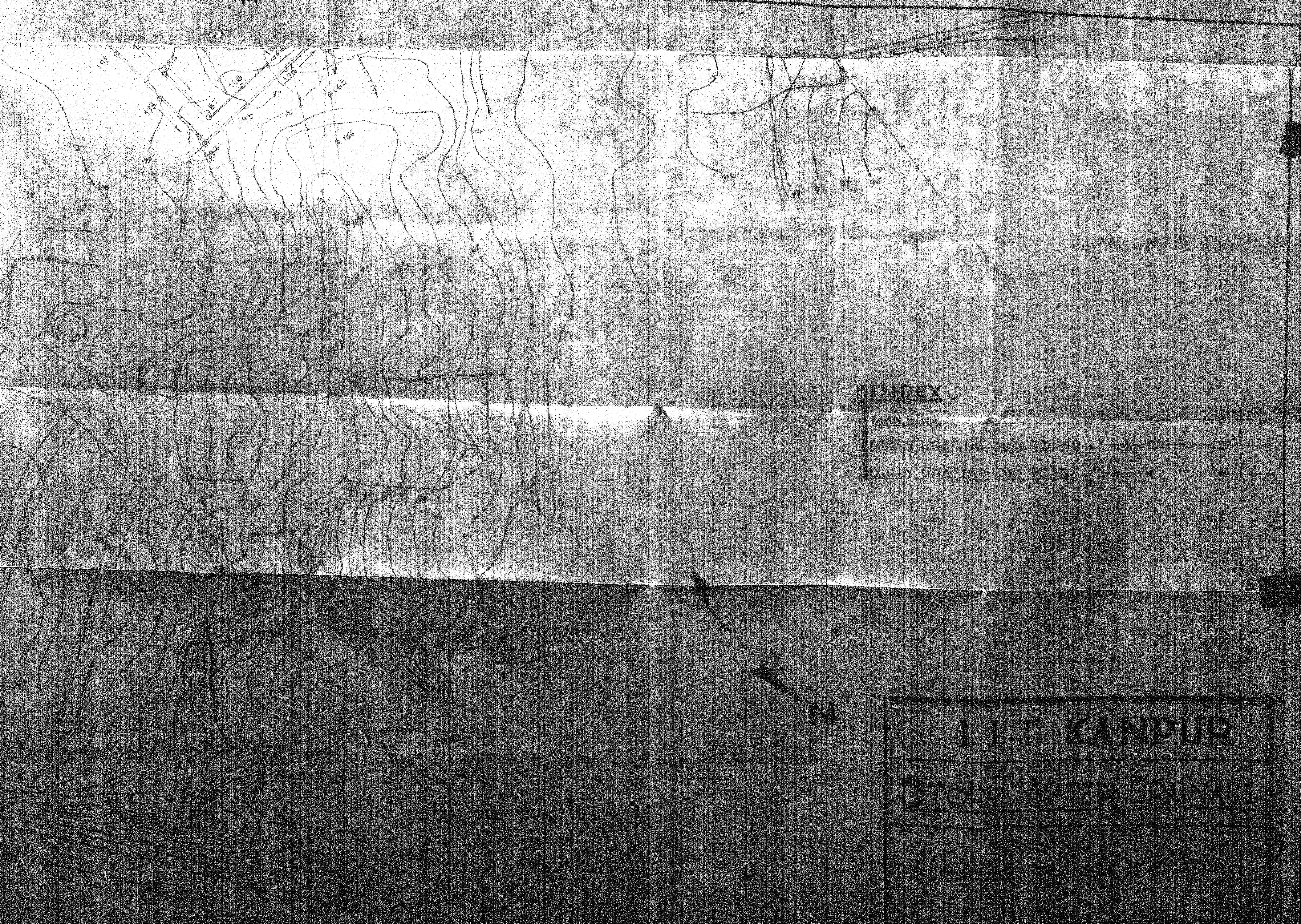

ALYANPUR DISTRIBUTRY




INDEX
MAN HOLE



GUMTI NO. 15
KANPUR
DELHI



I.I.T. KANPUR

STORM WATER DRAINAGE

FIG 3.2 MASTER PLAN OF I.I.T. KANPUR

near a ridge along which the Kalyanpur distributary flows. The distributary flows in the south west portion of the campus. The campus area is essentially to the north of the ridge line and it slopes towards the north and north east. Taking into consideration actual topography of the area, the campus is provided with four independent subsystems, as follows:

i) Subsystem I to the west of fifth avenue which drains to the north as indicated.

ii) Subsystem II bounded on west by the southern 'covered varandaha' through the acedemic buildings to the north, Kalyanpur distributary to the south and third avenue and its extension to the east.

iii) Subsystem III bounded by sixth avenue to the west, the third and fourth avenues as shown to the east, subsystem II to south and nursery road to the north. This drains to the north of the area as indicated.

iv) Subsystem IV includes all the area to the east of the subsystem II and is bounded on the north side by natural drainage to the north of the main drive. Subsystem II drains to its north east and subsystem IV to its north to the nala mentioned earlier, and

v) The area to north of zone IV and east of the zone III including the air strip is not provided with any drainage system because of natural topography.

3.2.1 Data for the system

The alignment of the drains provided in I.I.T. campus are available for the study. But engineering details including the size of the drains, their invert levels are not available and so could not be made use of in the study. The average slope of the pipe lines are estimated from toposheets and are considered to be uniform over each system. A detailed survey which could have been useful for the study could not be done because of time and resource limitations.

A detailed map of the campus showing the locations of buildings, roads, brick paths etc. were made available and are used in this study for estimating connected paved areas, unconnected paved areas and contributing grassed areas. In this study it is assumed that all the grassed areas are connected to the system. As indicated by Terstriep and Stall (12) a lot of grassed area may detain precipitation for a sufficiently long time so that outflow from such grassed area may not contribute to peak runoff. It is hoped that this assumption will not introduce much of error in the study. The soil in I.I.T. Kanpur campus is silty loam and it is considered to be moderately well drained and have moderate infiltration rates. It is classified as soil type B

of the U.S. Soil Conservation Service. The antecedent moisture condition used in the study correspond to ILLUDAS number 2 which represents a rather dry condition with a rainfall of 0.5 inch in the preceding five days. It seems preferable to use condition number 3 representing rather wet condition with a rainfall of 0.5 inch to 1 inch in the preceding five days and soil type C for the basin. Because of limitations of time and availability of computer time , the study could not be repeated for these conditions and so the results are to be used, if at all, with care. The Manning's roughness coefficient of 0.013 is used in the study.

3.3 Design Storm

Urban drainages are small and they have fairly low priority. They are costly. Hence they are to be designed for specific levels of risk and frequency of the design storms. For urban residential areas, it varies generally between 2 to 5 years. The duration of the storm precipitation is also variable and generally this duration should be comparable to the time of concentration for a rural basin or the sum of inlet and travel times for an urban basin. India Meteorological Department has published depth-duration-frequency relationships for the country. The generalised maps for depth-duration-frequency relationships over India

3.4 Details of Subsystems

Fig. 3.2 shows the master plan layout of I.I.T. Kanpur campus storm water drainage system. The details of drainage system connecting to main lines shown in the master plan layout are not available. Using field observations and judgement, appropriate lines are assumed for the subsystem and the details of subsystems are discussed in the following subsections.

3.4.1 Subsystem I

This is a residential area containing group houses, hostels etc. and paved roads with lawns, play grounds etc. The ground slopes are gentle (around 0.5 percent). It is an area of 113.9 acres of which 17.5 percent is paved area and rest is natural ground surface. The roads, streets and hostels are generally included into directly connected paved area and remainder of the paved area is considered as suplemental paved area. All the grassed area is considered to be contributing Fig. 3.3 indicates the numbering of main nodes and branches of the drainage system. The data for the subsystem is shown in Table 3.2.

3.4.2 Subsystem II

This is also a residential and acedemic area containing hostels, some houses and several civic facilities

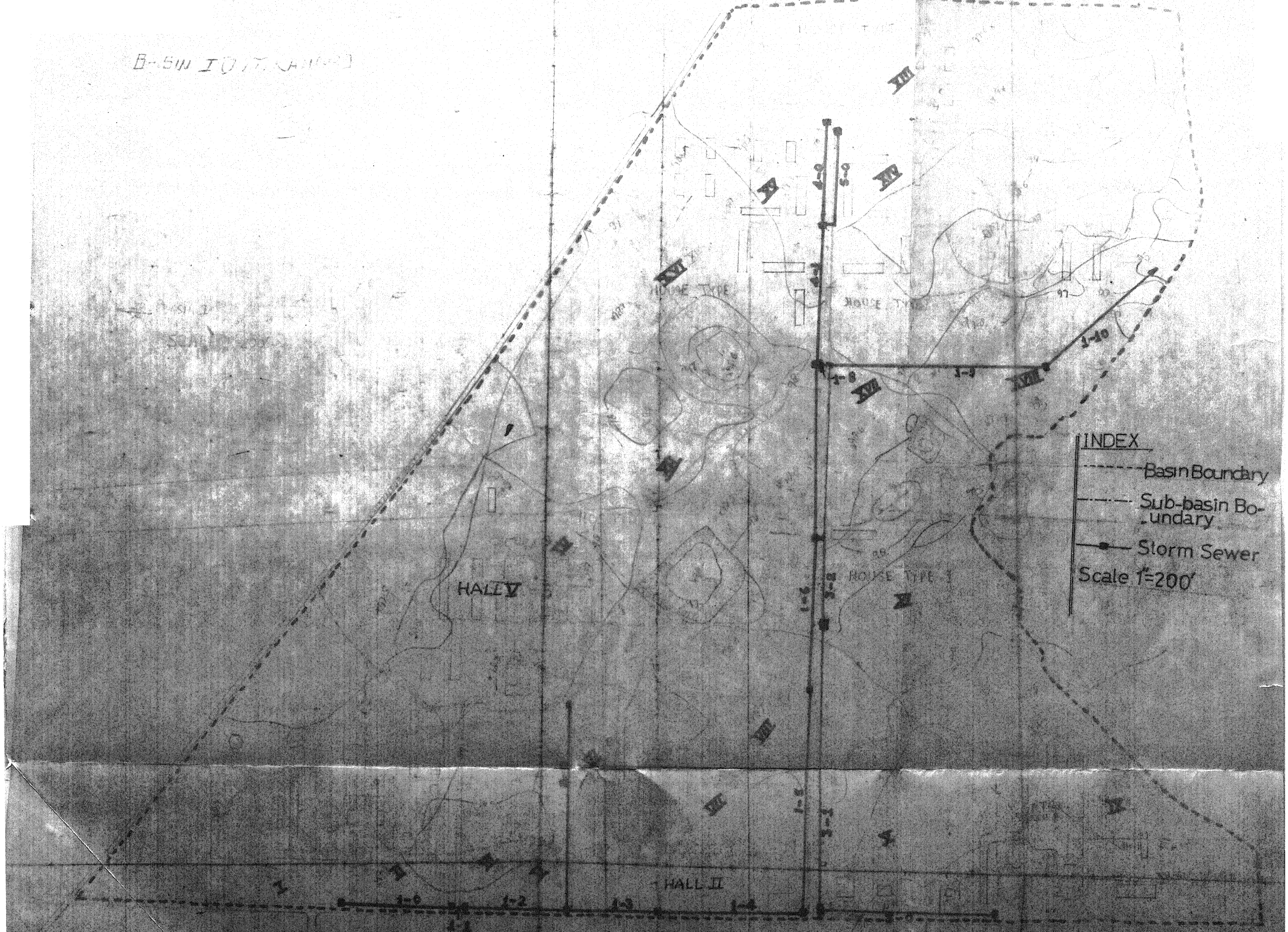


Fig. 3.3 Drainage Layout for Subsystem I of I.I.T.Kanpur

TABLE 3.2 : DATA OF SUBSYSTEM I OF I.I.T. KANPUR

Reach			Sub-basins				
Branch and Reach Number	Length (ft)	Slope (%)	Sub-basin Number	Area (acres)	Directly connected paved area (acres)	Supplemented paved area (acres)	Contributing grassed area (acres)
1	2	3	4	5	6	7	8
1-0	300	0.5	I	8.72	0.313	1.507	6.9
1-1	20	0.5	II	3.43	0.083	1.507	1.84
1-2	290	0.5	III	1.91	0.084	1.817	1.01
2-0	560	0.5	IV	10.40	0.368	3.014	7.018
CONFLUENCE							
1-3	240	0.5	V	1.91	0.084	0.817	1.01
1-4	400	0.5	VI	3.66	0.22	1.567	1.88
1-5	610	0.5	VII	3.39	0.211	0.22	2.96
1-6	420	0.5	VIII	4.64	0.08	1.287	3.273
3-0	480	0.5	IX	7.10	2.15	0.18	4.77
3-1	800	0.5	X	6.35	0.5	0.138	5.712
3-2	264	0.5	XI	8.15	0.05	0.138	7.962
CONFLUENCE							
1-7	476	0.5	XII	8.30	0.128	-	8.172
4-0	284	0.5	XIII	10.30	0.46	0.55	9.29
5-0	374	0.5	XIV	5.64	0.28	0.55	4.81

Contd...

Table 3.2 Contd...

1	2	3	4	5	6	7	8
CONFLUENCE							
4-1	390	0.5	XV	5.99	0.220	0.51	5.26
CONFLUENCE							
1-8	26	0.5	XVI	10.80	0.175	0.166	9.469
1-9	600	0.5	XVII	2.90	-	0.26	2.64
1-10	400	0.5	XVIII	10.3	-	0.37	9.93
			Total	113.89			

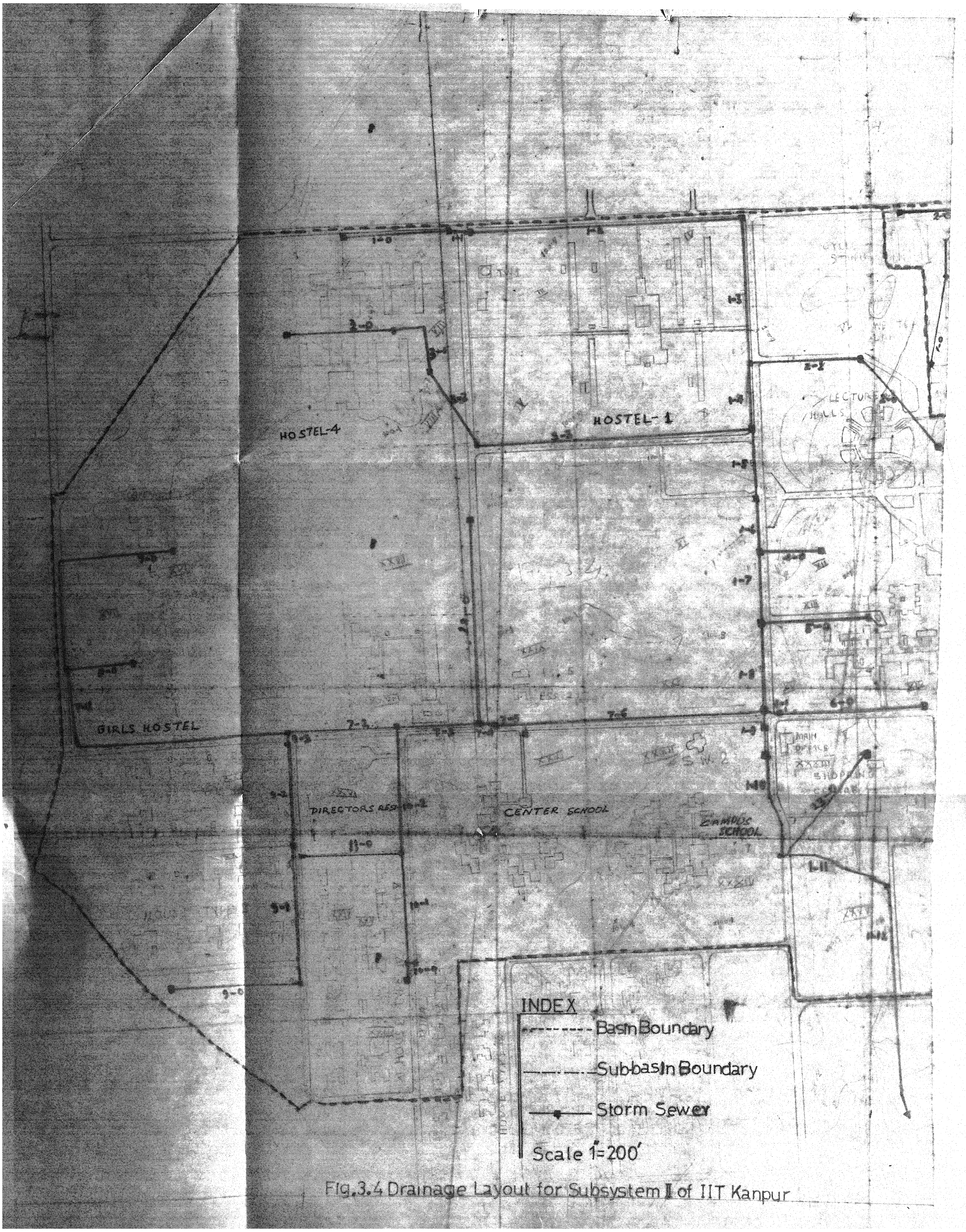


Fig.3.4 Drainage Layout for Subsystem II of IIT Kanpur

TABLE 3.3: DATA OF SUBSYSTEM II OF I.I.T. KANPUR

Reach			Sub-basins				
Branch and Reach Number	Length (ft)	Slope (%)	Sub-basin number	Area (acres)	Directly connected paved area (acres)	Supplemental paved area (acres)	Contributing grassed area (acres)
1	2	3	4	5	6	7	8
1-0	340	0.5	I	1.350	0.230	0.190	0.937
1-1	20	0.5	II	1.140	0.200	0.190	0.750
1-2	900	0.5	III	3.040	1.310	0.764	0.966
1-3	424	0.5	IV	2.750	0.190	0.764	1.800
2-0	350	0.5	V	2.740	1.800	-	0.940
2-1	334	0.5	VI	9.030	1.140	0.180	8.710
CONFLUENCE							
1-4	200	0.5	-	-	-	-	-
3-0	320	0.5	VII	3.070	-	0.180	2.890
3-1	80	0.5	VIII	1.840	-	0.180	1.660
3-2	250	0.5	VIIIA	6.980	-	0.450	6.530
3-3	820	0.5	IX	2.480	0.140	-	2.340
CONFLUENCE							
1-5	210	0.5	X	3.500	0.210	0.764	2.560
1-6	160	0.5	XI	9.900	1.200	-	8.700
4-0	180	0.5	XII	2.660	-	0.880	1.780

Contd....

Table 3.3 contd...

1	2	3	4	5	6	7	8
CONFLUENCE							
1-7	214	0.5	-	-	-	-	-
5-0	320	0.5	XIII	2.400	0.740	-	1.660
CONFLUENCE							
1-8	266	0.5	-	-	-	-	-
6-0	450	0.5	XIV	1.450	-	0.37	1.080
6-1	20	0.5	XV	1.540	0.420	0.180	0.930
CONFLUENCE							
7-0	800	0.5	XVI	3.190	1.090	-	2.100
8-0	200	0.5	XVII	3.220	0.600	0.330	2.290
CONFLUENCE							
7-1	858	0.5	-	-	-	-	-
9-0	80	0.5	XVIII	1.220	0.26	0.170	0.790
9-1	350	0.5	XIX	5.370	0.514	0.210	4.650
9-2	310	0.5	XX	5.930	0.480	0.420	5.630
9-3	20	0.5	XXI	2.270	0.360	0.210	1.700
CONFLUENCE							
7-2	330	0.5	XXII	5.410	0.450	0.230	4.960
10-0	66	0.5	XXIII	1.370	0.260	0.170	0.940
10-1	344	0.5	XXIIIA	1.480	0.110	0.210	1.160
11-0	300	0.5	XXIV	1.400	0.120	0.127	1.150

Table 3.3 contd....

1	2	3	4	5	6	7	8
CONFLUENCE							
7-3	240	5.0	XXVI	2.55	0.413	0.147	1.99
12-0	600	5.0	XXVII	8.32	0.100	0.294	7.926
CONFLUENCE							
7-4	30	5.0	XXVIII	3.19	0.340	0.732	2.170
7-5	100	5.0	XXIX	2.40	0.370	0.110	1.920
7-6	720	5.0	XXX	9.60	0.76	0.815	8.025
CONFLUENCE							
1-9	30	5.0	XXXI	3.46	0.320	0.470	2.670
1-10	488	5.0	XXXII	4.980	0.230	0.390	4.360
13-0	400	5.0	XXXIII	3.080	-	0.220	2.860
CONFLUENCE							
1-11	340	5.0	XXXIII	2.440	0.710	-	1.730
1-12	122	5.0	XXXV	7.050	1.230	-	5.820
		Total		138.84			

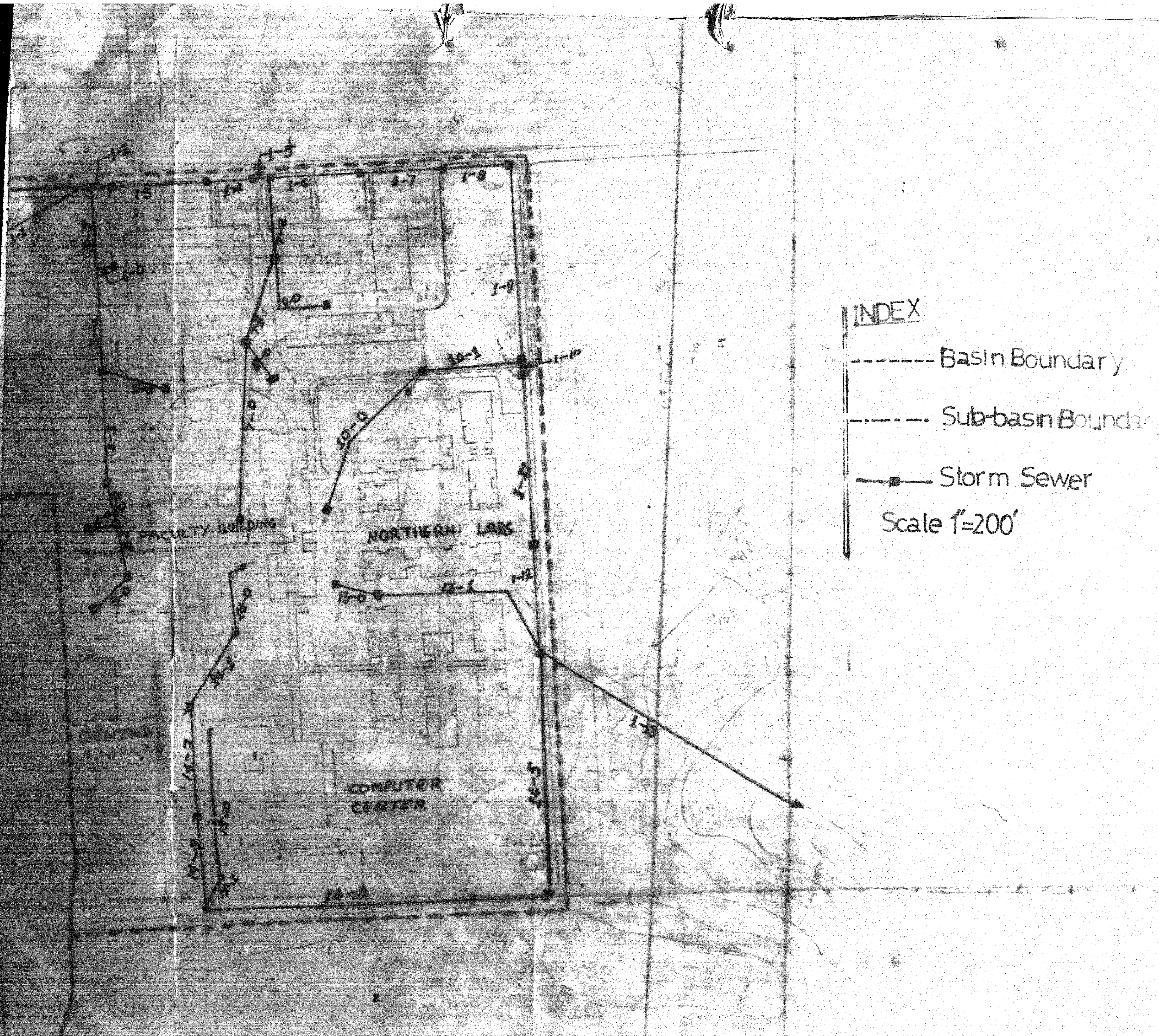


Fig. 3.5 Drainage Layout for Su~~d~~system II of I.I.T. Kanpur
b

TABLE 3.4 DATA OF SUBSYSTEM III OF I.I.T. KANPUR

Reach			Sub-basins				
Branch and Reach Number	Length (ft)	Slope (%)	Sub-basin number	Area (acres)	Directly connected paved area (acres)	Supplemental paved area (acres)	Contributing grassed area (acres)
1	2	3	4	5	6	7	8
1-0	265	0.5	I	0.522	-	0.258	0.226
1-1	310	0.5	II	1.160	-	0.249	0.908
2-0	320	0.5	IV	0.722	0.722	-	-
CONFLUENCE							
3-0	85	0.5	V	0.402	-	0.074	0.343
3-1	110	0.5	VI	0.120	-	0.072	0.046
4-0	40	0.5	VII	0.167	-	0.085	0.082
CONFLUENCE							
3-2	825	0.5	VII	0.180	-	0.095	0.085
3-3	230	0.5	IX	0.440	-	0.282	0.152
5-0	135	0.5	XI	0.445	-	0.17	0.275
CONFLUENCE							
3-4	195	0.5	XA	0.714	-	0.342	0.372
6-0	20	0.5	XII	0.316	0.038	0.187	0.092
CONFLUENCE							
3-5	170	0.5	XB	0.343	0.032	0.169	0.173

Table 3.4 contd...

1	2	3	4	5	6	7	8
CONFLUENCE							
1-2	30	0.5	III	1.080	0.113	0.184	0.735
1-3	190	0.5	XIII	0.357	0.075	0.121	0.161
1-4	95	0.5	XIV	0.535	0.087	0.238	0.211
1-5	25	0.5	XV	0.299	0.097	0.166	0.037
7-0	355	0.5	XVI	0.858	-	0.437	0.62
8-0	85	0.5	XVII	0.198	-	0.477	0.44
CONFLUENCE							
7-1	175	0.5	XVIII	1.200	-	0.651	0.547
9-0	205	0.5	XIX	0.772	-	0.541	0.23
CONFLUENCE							
7-2	165	0.5	-	-	-	-	-
CONFLUENCE							
1-6	195	0.5	XX	0.334	0.072	0.099	0.169
1-7	155	0.5	XXI	0.524	0.064	0.196	0.265
1-8	140	0.5	XXII	1.050	0.352	0.294	0.400
1-9	375	0.5	XXIII	0.894	0.295	-	0.565
10-0	350	0.5	XXIV	1.520	-	0.300	1.215
10-1	210	0.5	XXV	0.435	0.063	0.127	0.245

Table 3.4 contd...

1	2	3	4	5	6	7	8
CONFLUENCE							
1-10	25	0.5	XXVI	0.899	0.167	-	0.732
1-11	340	0.5	XXVII	0.709	0.138	0.236	0.334
1-12	220	0.5	XXVIV	1.520	0.167	0.259	1.090
13-0	85	0.5	XXIX	0.330	-	0.172	0.159
13-1	370	0.5	XXX	1.210	-	0.500	0.703
CONFLUENCE							
14-0	145	0.5	XXXII	0.744	-	0.380	0.363
14-1	170	0.5	XXXIII	0.903	-	0.248	0.657
14-2	260	0.5	XXXIV	1.660	1.12	0.121	0.248
14-3	195	0.5	XXXV	0.870	0.081	0.155	0.657
15-0	300	0.5	XXXVI	0.940	0.276	0.179	0.484
15-1	70	0.5	XXXVI	1.530	0.484	-	1.050
CONFLUENCE							
14-4	690	0.5	XXXVIII	1.250	0.133	0.081	1.038
14-5	45	0.5	XXXIX	1.595	0.034	0.074	1.458
CONFLUENCE							
1-13	60810	0.5	XXXI	4.620	0.351	0.565	3.700
			Total	34.184			

including Health Centre, Campus School, Central school and the Shopping Centre as well as a part of the Library and some of laboratories. It has an area of 134.8 acres of which 20 percent is paved and the grassed slope is generally less than 1 percent. The roads, streets, and residential houses are considered as directly connected and all the grassed areas are considered to be contributing. The details of nodes and branches of the subsystem are shown in Fig. 3.4 and details of subsystem are given in Table 3.3.

3.4.3 Subsystem III

This is essentially are acedemic area containing Faculty building, laboratories workshopes, streets, brick foot paths etc. It has an area of 34.2 acres of which 40 percent is paved and it has a slope of about 0.5 percent. All the roads, parking lots, and parts of the built up area are included in the directly connected paved area and as in the earlier cases the entire grassed area is assumed to be contributing. The details are given in Table 3.4 and Fig. 3.5.

3.4.4 Subsystem IV

This is an essentially homogeneous residential area with well defined drainage boundaries and a general slope of

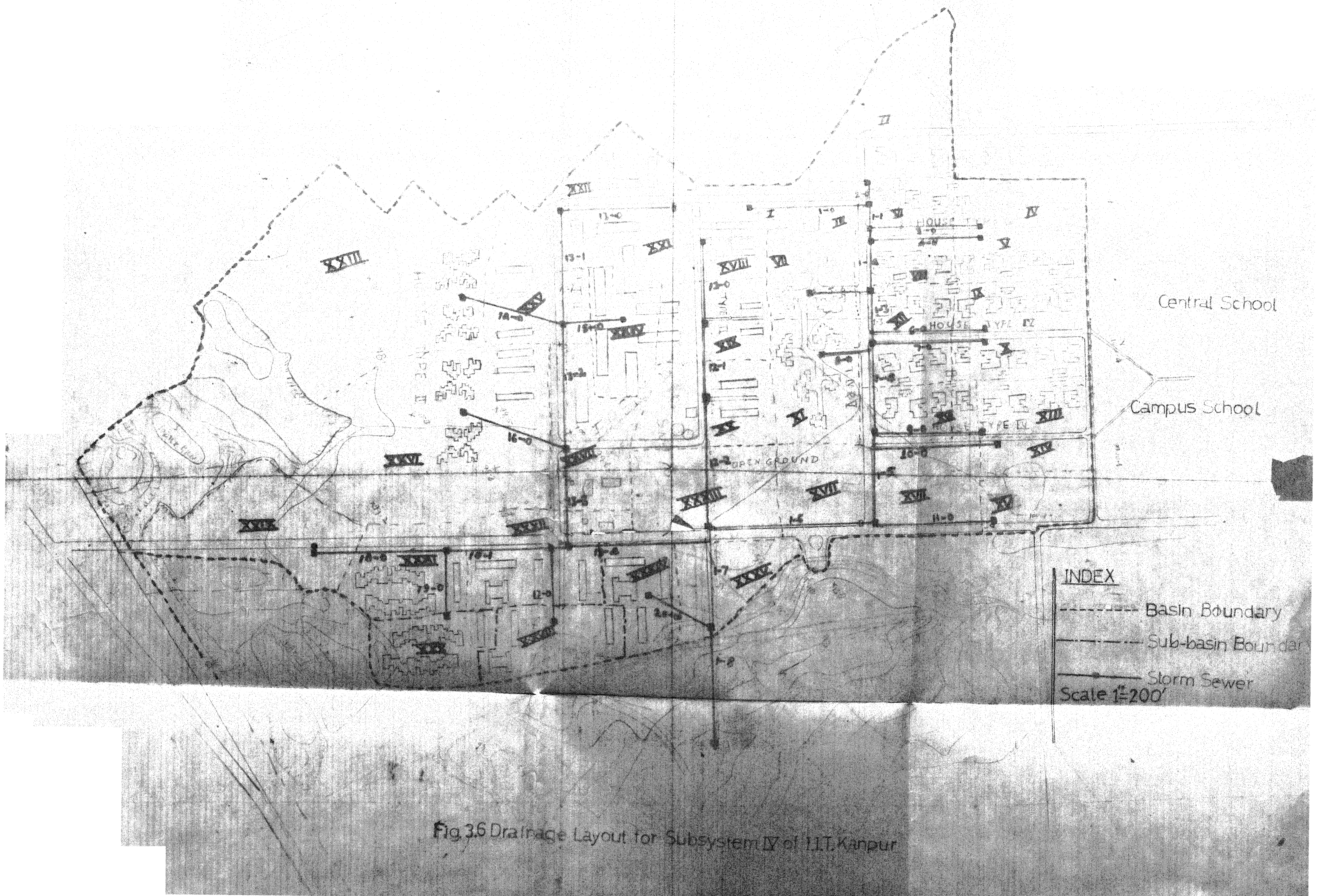


Fig.3.6 Drainage Layout for Subsystem IV of I.I.T. Kanpur

TABLE 3.5 : DATA OF SUBSYSTEM IV OF I.I.T. KANPUR

Reach			Sub-basins				
Branch and Reach Number	Length (ft.)	Slope (%)	Sub-basin number	Area (acres)	Directly connected paved area (acres)	Supplemental paved area (acres)	Contributing grassed area (acres)
1	2	3	4	5	6	7	8
1-0	340	1	I	0.877	0.145	0.046	0.686
2-0	60	1	II	2.443	0.177	0.164	2.102
CONFLUENCE							
1-1	70	1	III	0.842	0.096	0.098	0.649
3-0	320	1	IV	1.349	0.088	0.183	1.078
CONFLUENCE							
4-0	320	1	V	1.349	0.088	0.305	0.956
CONFLUENCE							
1-2	180	1	VI	0.77	0.071	0.110	0.589
5-0	180	1	VIII	1.454	0.531	-	0.923
CONFLUENCE							
1-3	120	1	VIII	0.998	0.159	0.166	0.673
6-0	340	1	IX	1.349	0.688	0.305	0.956
CONFLUENCE							
7-0	340	1	X	1.349	0.088	0.305	0.956

Table 3.5 contd....

1	2	3	4	5	6	7	8
CONFLUENCE							
8-0	120	1	XI	2.509	0.639	-	1.870
CONFLUENCE							
1-4	290	1	XII	1.838	0.227	0.332	1.279
9-0	320	1	XIII	1.349	0.088	0.305	0.956
CONFLUENCE							
10-0	360	1	XIV	0.738	0.092	-	0.646
CONFLUENCE							
1-5	260	1	XV	0.956	0.216	0.183	0.566
11-0	370	1	XVI	1.249	0.142	-	1.107
CONFLUENCE							
1-6	480	1	XVII	3.511	0.497	-	3.064
12-0	240	1	XVIII	0.692	0.131	-	0.561
12-1	220	1	XIX	1.667	0.137	0.154	1.376
12-2	380		XX	2.09	0.220	0.129	1.741
CONFLUENCE							
13-0	330	1	XXI	2.156	0.159	0.224	1.773
13-1	330	1	XXII	1.303	0.124	0.193	0.986
14-0	300	1	XXIII	7.242	0.426	-	6.822
CONFLUENCE							
15-0	180	1	XXIV	1.495	-	0.363	1.132

Table 3.5 contd...

1	2	3	4	5	6	7	8
CONFLUENCE							
13-2	360	1	XXV	2.326	0.127	0.221	1.98
16-0	310	1	XXVI	6.887	0.426	0.221	6.24
CONFLUENCE							
13-3	290	1	XXVII	2.357	0.319	0.170	1.868
17-0	240	1	XXVIII	1.668	0.088	0.227	1.353
CONFLUENCE							
18-0	380	1	XXIX	3.656	0.437	-	3.219
19-0	180	1	XXX	1.476	-	0.423	1.053
CONFLUENCE							
18-1	300	1	XXXI	1.738	0.221	0.423	1.094
CONFLUENCE							
13-4	400	1	XXXII	2.618	0.501	0.159	2.023
CONFLUENCE							
1-7	280	1	XXXIII	2.683	0.313	-	2.371
20-0	200	1	XXXIV	1.235	0.011	0.225	0.969
CONFLUENCE							
1-8	340	1	XXXV	1.118	-	-	1.118
			Total	69.4			

less than 1 percent. The area of the basin is 69.4 acres of which 17 percent is paved. The street, roads, and half of the built up area are included in the directly connected paved area and all the grassed areas are assumed to be contributing. The layout of the drainage system with the major nodes and branches are given in Fig. 3.6 and details are given in Table 3.5.

3.5 Simulation Analysis

Simulation analysis was performed for each of the subsystems generally for storms with a period of 30, 45, and 60 minutes and a frequency of 2, 5, 10 and 25 years. Since the programme is used in the design mode, the programme routes the storm precipitation through the drainage system, estimates appropriate diameters and also indicates the hydrographs of runoff at the outlet, the maximum discharge at intermediate nodes and pipe lines, and the total amount of accumulated runoff. The design diameter in inches and peak discharge in cusecs for each of the branches for each combination of frequency and duration are shown in Tables 3.6, 3.7, 3.8 and 3.9 respectively for subsystem I, II, III, and IV. The variation of design diameter and discharge along the main storm sewers are also shown in Figs. 3.7, 3.8, 3.9 and 3.10 for subsystems I,

TABLE_3·6 : DESIGN DIAMETER AND PEAK DISCHARGE FOR SUB-SYSTEM I OF I.I.T. KANPUR.

FREQUNCY→		2 YEARS						5 YEARS						10 YEARS						25 YEARS					
SR. NO.	BRCH — RCH	DIAMETER OF PIPE. (INCHES)			DISCHARGE (cfs.)			DIAMETER OF PIPE. (INCHES)			DISCHARGE (cfs.)			DIAMETER OF PIPE. (INCHES)			DISCHARGE (cfs.)			DIAMETER OF PIPE. (INCHES)			DISCHARGE (cfs.)		
		30 MIN.	45 MIN.	60 MIN.	30 MIN.	45 MIN.	60 MIN.	30 MIN.	45 MIN.	60 MIN.	30 MIN.	45 MIN.	60 MIN.	30 MIN.	45 MIN.	60 MIN.	30 MIN.	45 MIN.	60 MIN.	30 MIN.	45 MIN.	60 MIN.	30 MIN.	45 MIN.	60 MIN.
1	1-0	18	15	12	9.23	5.46	3.1	21	21	21	15.4	13.5	10.98	24	24	24	11.75	18.82	18.25	27	27	27	29.22	27.14	27.02
2	1-1	24	18	18	15.97	10.05	7.6	27	24	24	24.23	22.18	18.64	27	27	27	28.47	29.67	29.49	33	33	33	44.49	42.2	41.78
3	1-2	24	21	18	19.87	12.84	10.17	27	27	27	29.18	26.98	22.91	30	30	30	33.96	35.90	35.77	36	33	33	53.16	50.43	50.00
4	2-0	21	18	18	14.54	10.01	8.27	24	24	24	21.72	20.77	17.73	27	27	27	24.77	27.16	27.43	30	30	30	39.86	38.8	37.97
5	1-3	30	27	24	38.57	25.79	21.0	36	33	33	56.18	52.46	45.22	36	39	39	66.55	69.15	69.05	45	42	42	102.09	95.74	94.80
6	1-4	33	30	27	44.99	31.54	25.75	36	36	36	65.78	61.66	53.65	39	39	39	75.74	80.25	80.44	45	45	45	117.56	110.19	109.04
7	1-5	33	30	27	47.11	33.39	26.22	39	36	36	69.55	65.45	56.58	39	42	42	80.67	86.13	84.98	48	45	45	125.53	118.48	116.93
8	1-6	36	30	27	54.03	37.87	29.78	39	39	36	81.08	74.86	64.81	42	42	42	92.67	99.97	97.23	51	48	48	147.42	135.64	132.55
9	3-0	24	21	21	17.60	11.22	10.80	27	24	21	23.54	18.98	15.62	27	27	24	26.07	23.37	21.30	30	27	27	37.42	30.24	27.48
10	3-1	24	21	21	21.60	15.47	13.93	30	27	24	32.41	29.20	20.78	30	30	27	37.04	37.68	30.85	36	33	33	57.21	48.14	42.28
11	3-2	27	24	24	30.35	19.68	17.54	33	33	27	49.41	41.16	29.07	36	36	33	55.94	54.54	46.45	42	39	39	90.46	73.42	67.78
12	1-7	39	33	33	82.12	52.65	43.4	48	45	42	130.5	118.08	93.79	51	51	51	152.02	159.15	149.05	60	57	57	247.72	224.52	211.19
13	4-0	18	12	12	7.81	3.44	2.31	21	21	18	14.9	12.8	8.61	24	24	24	17.91	18.10	17.08	30	27	27	31.45	27.71	26.50
14	5-0	15	12	12	5.11	2.74	1.41	18	18	15	9.00	7.89	5.76	21	21	18	10.65	10.80	10.40	24	24	21	18.08	16.17	15.68
15	4-1	24	18	15	19.49	8.33	5.03	30	27	24	34.52	28.05	20.18	33	30	30	41.93	39.73	37.79	39	36	36	77.90	60.01	58.51
16	1-8	45	36	33	102.77	59.49	47.34	54	51	45	173.42	154.33	117.8	57	57	57	205.08	214.45	199.91	69	66	63	341.14	305.84	293.04
17	1-9	45	36	33	104.80	60.16	47.3	54	51	45	177.22	157.97	119.87	57	57	57	209.68	219.46	204.73	69	66	66	349.54	313.71	301.10
18	1-10	45	36	33	113.39	61.32	46.12	54	54	48	192.48	169.03	126.8	57	60	57	225.71	236.71	220.25	72	69	66	380.53	340.89	326.11

TABLE 3.17 DESIGN DIAMETER AND PEAK DISCHARGE OF SUB-SYSTEM II OF I.I.T. KANPUR

DIAMETER IN INCHES												DESIGN DISCHARGE IN C.F.S.											
2 YEARS			5 YEARS			10 YEARS			25 YEARS			2 YEARS			5 YEARS			10 YEARS			25 YEARS		
30 MIN	45 MIN	60 MIN	30 MIN	45 MIN	60 MIN	30 MIN	45 MIN	60 MIN	30 MIN	45 MIN	60 MIN	30 MIN	45 MIN	60 MIN	30 MIN	45 MIN	60 MIN	30 MIN	45 MIN	60 MIN	30 MIN	45 MIN	60 MIN
[illegible]	[illegible]	[illegible]	15	15	12	15	15	15	18	[illegible]	15	2.40	3.49	3.28	3.27	3.04	2.36	3.68	3.81	3.38	5.40	5.02	4.52
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15	18	18	18	21	[illegible]	21	4.27	6.48	6.11	6.30	5.76	4.33	7.11	7.20	6.39	10.84	9.51	8.37
[illegible]	[illegible]	[illegible]	27	27	24	27	27	27	33	[illegible]	30	14.03	14.41	16.54	19.31	18.2	15.27	21.20	21.66	19.81	29.65	27.21	24.6
[illegible]	[illegible]	[illegible]	[illegible]	27	27	30	30	30	36	[illegible]	33	18.64	23.90	23.49	25.62		19.29	27.56	27.04	26.21	41.94	35.22	33.64
[illegible]	[illegible]	[illegible]	27	24	24	27	24	24	30	[illegible]	27	13.47	12.28	11.74	17.64	12.84	11.74	18.56	14.93	14.54	25.39	18.20	17.58
[illegible]	[illegible]	[illegible]	33	33	30	33	33	33	39	[illegible]	36	21.48	34.82	29.87	31.66	30.1	23.01	36.06	36.94	32.38	55.55	50.08	43.67
[illegible]	[illegible]	[illegible]	42	39	36	42	42	39	48	[illegible]	45	39.98	55.93	53.71	60.04	47.98	39.12	64.10	61.76	57.11	99.68	84.57	75.54
[illegible]	[illegible]	[illegible]	15	15	12	18	18	18	21	[illegible]	21	1.8	6.36	6.17	3.88	3.15	2.10	4.76	5.04	4.65	8.88	7.99	7.8
[illegible]	[illegible]	[illegible]	18	18	15	21	21	21	24	[illegible]	24	3.11	10.30	9.96	6.46	5.51	3.65	7.93	8.44	7.74	14.58	13.06	12.73
[illegible]	[illegible]	[illegible]	24	24	21	27	27	27	33	[illegible]	33	7.36	24.88	24.05	15.46	12.88	8.60	18.96	20.67	18.49	34.94	31.42	30.66
[illegible]	[illegible]	[illegible]	27	24	21	30	30	30	36	[illegible]	33	8.83	29.44	28.45	18.65	15.77	10.38	23.30	23.94	22.18	42.07	37.51	36.35
[illegible]	[illegible]	[illegible]	45	42	39	48	48	45	57	[illegible]	54	52.05	92.74	85.60	83.14	62.19	53.45	92.41	92.52	84.73	149.13	128.67	119.51
[illegible]	[illegible]	[illegible]	48	48	42	51	51	48	60	[illegible]	57	50.73	112.89	105.05	97.40	75.3	62.92	110.82	109.97	100.87	180.33	154.91	146.15
[illegible]	[illegible]	[illegible]	18	18	18	18	18	18	21	[illegible]	21	3.63	7.43	7.27	3.54	5.46	4.82	6.43	7.27	7.33	10.66	10.13	10.05
[illegible]	[illegible]	[illegible]	51	48	42	51	51	51	63	60	57	65.04	118.82	111.62	102.57	79.95	67.61	117.33	116.96	106.15	189.29	163.78	154.61
[illegible]	[illegible]	[illegible]	21	18	18	21	21	18	24	[illegible]	21	5.94	7.03	6.32	7.97	6.33	5.20	8.85	7.82	7.13	12.70	10.16	9.23
[illegible]	[illegible]	[illegible]	51	48	45	24	24	51	63	[illegible]	60	69.69	123.41	116.89	109.37	85.88	71.42	123.39	122.16	113.22	207.14	173.12	161.39
[illegible]	[illegible]	[illegible]	15	15	12	15	15	15	18	[illegible]	18	1.67	3.76	3.67	2.65	2.56	2.13	3.09	3.47	3.50	5.31	5.02	4.98
[illegible]	[illegible]	[illegible]	18	18	18	21	21	18	24	[illegible]	21	4.49	7.29	7.17	6.81	6.07	4.99	7.51	7.70	7.41	11.60	10.74	10.04
[illegible]	[illegible]	[illegible]	24	21	21	24	21	21	27	[illegible]	24	8.64	9.81	8.91	11.48	9.04	7.56	12.68	11.07	10.19	18.10	14.24	13.05
[illegible]	[illegible]	[illegible]	18	18	18	21	21	21	24	[illegible]	24	5.82	8.28	7.57	8.02	7.13	5.55	8.96	8.98	7.88	13.17	11.86	10.58
[illegible]	[illegible]	[illegible]	27	27	24	27	27	27	33	[illegible]	30	13.41	17.97	16.05	18.93	16.29	12.35	21.28	20.06	17.08	31.91	26.93	22.65
[illegible]	[illegible]	[illegible]	15	15	12	15	15	15	18	[illegible]	15	2.51	3.35	3.05	3.39	3.02	2.42	3.77	3.73	3.33	5.44	4.85	4.32
[illegible]	[illegible]	[illegible]	24	21	21	24	24	24	27	[illegible]	27	7.71	15.75	12.92	11.59	16.86	7.59	13.46	14.23	12.19	21.87	19.52	17.69
[illegible]	[illegible]	[illegible]	27	27	24	30	30	30	36	[illegible]	33	14.24	26.81	25.12	23.17	19.53	13.72	26.60	26.44	23.53	41.38	36.82	34.05
[illegible]	[illegible]	[illegible]	30	30	27	33	33	33	39	[illegible]	36	18.04	31.48	30.35	29.32	23.58	17.34	32.94	31.74	29.09	52.09	43.51	41.03
[illegible]	[illegible]	[illegible]	39	36	33	42	42	39	48	[illegible]	45	54.92	59.68	57.60	54.91	44.09	35.02	62.25	58.47	56.70	99.40	83.17	73.60
[illegible]	[illegible]	[illegible]	15	15	12	15	15	15	18	[illegible]	18	2.56	3.39	3.50	3.61	3.15	2.47	3.91	3.93	3.47	5.71	5.16	4.63
[illegible]	[illegible]	[illegible]	18	18	15	18	18	18	21	[illegible]	21	4.09	6.87	6.53	6.18	5.77	4.22	7.06	7.85	6.46	11.05	9.86	8.97
[illegible]	[illegible]	[illegible]	12	12	12	15	15	15	18	[illegible]	15	1.51	3.05	2.99	2.43	2.27	1.59	2.84	2.97	2.74	4.71	4.13	3.98
[illegible]	[illegible]	[illegible]	24	21	21	24	24	24	27	[illegible]	27	8.15	13.04	12.66	12.56	10.89	8.03	14.10	13.84	12.58	21.86	19.06	17.54
[illegible]	[illegible]	[illegible]	45	39	36	45	45	45	54	[illegible]	51	46.14	80.33	74.94	72.37	58.03	46.58	83.18	78.43	74.19	129.38	109.38	104.57
[illegible]	[illegible]	[illegible]	21	21	18	24	24	24	30	[illegible]	27	4.75	16.72	16.27	10.40	8.32	5.55	12.80	13.18	12.19	23.60	21.18	20.39
[illegible]	[illegible]	[illegible]	48	45	39	51	48	48	60	[illegible]	54	54.60	104.54	99.02	89.37	73.33	56.54	102.45	101.29	94.93	164.99	142.10	135.15
[illegible]	[illegible]	[illegible]	48	45	42	51	51	48	60	57	57	57.44	109.78	104.09	94.01	76.79	59.35	107.87	105.98	99.71	173.78	149.17	141.87
[illegible]	[illegible]	[illegible]	51	48	42	54	54	51	63	[illegible]	60	66.57	130.58	124.50	110.07	90.02	69.90	127.06	125.00	117.13	205.40	176.95	168.67
[illegible]	[illegible]	[illegible]	66	63	57	69	69	69	84	78	78	136.59	269.97	267.21	221.85	192.10	148.54	254.67	266.89	239.92	417.03	370.33	349.15
[illegible]	[illegible]	[illegible]	69	66	57	69	72	69	84	78	78	140.15	280.56	267.61	228.81	198.33	153.17	263.60	275.62	248.36	432.43	383.83	361.89
[illegible]	[illegible]	[illegible]	18	15	12	18	18	18	21	[illegible]	21	1.92	6.48	6.30	4.00	3.51	2.26	4.89	5.20	4.85	9.06	8.17	8.01
[illegible]	[illegible]	[illegible]	66	63	57	72	72	69	87	81	81	148.75	291.12	278.36	237.27	206.19	155.60	276.46	288.83	258.35	452.55	401.64	377.06
[illegible]	[illegible]	[illegible]	69	66	60	72	75	72	87	84	81	155.26	333.75	291.14	246.89	214.13	162.03	290.61	300.60	270.70	477.64	419.81	393.63

TABLE 3:7 DESIGN

SR. NO.	BRCH-RCH.	DIAMETER IN INCHES									
		2 YEARS			5 YEARS			10 YEARS			
		30 MIN	45 MIN	60 MIN	30 MIN	45 MIN	60 MIN	30 MIN	45 MIN	60 MIN	30 M
1	1-0	12	15	15	15	15	12	15	15	15	18
2	1-1	15	18	18	18	[illegible]	15	18	18	18	21
3	1-2	24	27	27	27	27	24	27	27	27	33
4	1-3	27	30	30	[illegible]	27	27	30	30	30	36
5	2-0	24	24	[illegible]	27	24	24	27	24	24	30
6	2-1	27	33	33	33	33	30	33	33	33	39
7	1-4	36	[illegible]	39	42	39	36	42	42	39	48
8	3-0	12	18	18	15	15	12	18	18	18	21
9	3-1	[illegible]	21	21	18	18	15	21	21	21	24
10	[illegible]	18	30	30	24	24	21	27	27	27	33
11	3-3	21	33	30	27	24	21	30	30	30	36
12	1-5	39	48	48	45	42	39	48	48	45	57
13	1-6	42	51	51	48	45	42	51	51	48	60
14	4-0	15	21	18	18	18	18	18	18	18	21
15	1-7	42	51	51	51	45	42	51	51	51	63
16	5-0	18	18	18	21	18	18	21	21	18	24
17	1-8	42	54	51	51	48	45	24	24	51	63
18	6-0	12	15	15	15	15	12	15	15	15	18
19	6-1	15	18	18	18	18	18	21	21	18	24
20	7-0	21	21	21	24	21	21	24	21	21	27
21	8-0	18	21	21	21	18	18	21	21	21	24
22	7-1	24	27	27	27	27	24	27	27	27	33
23	9-0	12	15	15	15	15	12	15	15	15	18
24	9-1	21	24	24	24	21	21	24	24	24	27
25	9-2	24	30	30	30	27	24	30	30	30	36
26	9-3	27	33	30	33	30	27	33	33	33	39
27	7-2	33	42	39	39	36	33	42	42	39	48
28	10-0	15	15	15	15	15	12	15	15	15	18
29	10-1	15	18	18	18	18	15	18	18	18	21
30	11-0	12	15	15	12	12	12	15	15	15	18
31	10-2	21	24	24	24	21	21	24	24	24	27
32	7-3	36	45	45	45	39	36	45	45	45	54
33	12-0	18	27	27	21	21	18	24	24	24	30
34	7-4	39	51	48	48	45	39	51	48	48	60
35	7-5	39	51	51	48	45	42	51	51	48	60
36	7-6	42	54	54	51	48	42	54	54	51	63
37	1-9	54	72	69	66	63	57	69	69	69	84
38	1-10	57	72	72	66	63	57	69	72	69	84
39	13-0	12	18	18	15	15	12	18	18	18	21
40	1-11	57	72	72	66	63	57	72	72	69	87
41	1-12	57	75	72	69	66	60	72	75	72	87

SCHARGE OF SUB-SYSTEM III, OF I.I.T. KANPUR.

DESIGN DISCHARGE IN CFS.											
2 YEARS			5 YEARS			10 YEARS			25 YEARS.		
30 MIN	45 MIN	60 MIN	30 MIN	45 MIN	60 MIN	30 MIN	45 MIN	60 MIN.	30 MIN	45 MIN	60 MIN.
1.0	0.82	0.8	1.43	1.46	1.33	1.62	1.82	1.83	2.48	2.38	2.37
2.2	1.49	1.23	3.42	3.32	2.80	3.94	4.39	4.39	6.45	6.12	6.06
5.28	3.69	3.43	6.55	4.95	4.60	7.09	5.73	5.49	9.51	6.96	6.46
0.39	0.19	0.10	0.67	0.61	0.47	0.79	0.87	0.86	1.39	1.30	1.29
0.68	0.45	0.34	1.07	1.00	0.82	1.24	1.55	1.32	2.06	1.91	1.88
0.33	0.28	0.27	0.47	0.48	0.44	0.53	0.59	0.60	0.80	0.77	0.77
1.38	1.04	0.91	2.07	2.01	1.74	2.37	2.59	2.57	3.77	3.53	3.48
2.53	2.03	1.89	3.60	3.56	3.20	4.03	4.44	4.43	6.19	5.87	5.58
0.67	0.51	0.45	1.01	1.02	0.91	1.16	1.32	1.13	1.89	1.80	1.79
4.5	3.63	3.38	6.48	6.50	5.86	7.33	8.08	8.07	11.36	10.82	10.72
0.83	0.73	0.73	1.05	1.08	1.03	1.16	1.28	1.31	1.64	1.60	1.62
5.99	4.95	4.69	8.50	8.56	7.85	9.55	10.61	10.64	14.66	13.85	13.75
14.44	10.07	8.90	19.25	16.78	14.75	21.39	20.62	19.99	31.30	26.72	13.88
14.97	10.79	9.48	20.46	17.89	15.10	22.65	21.79	21.13	33.21	28.13	15.36
16.26	11.52	10.50	22.17	19.23	16.78	24.96	23.53	22.95	36.28	30.60	17.78
17.40	12.46	11.32	23.59	20.35	17.96	26.44	24.91	24.16	37.94	32.20	19.47
1.69	1.42	1.37	2.41	2.45	2.25	2.72	3.04	3.06	4.13	3.96	3.94
1.84	1.56	1.51	2.62	2.67	2.45	2.95	3.30	3.32	4.46	4.28	4.26
6.11	5.16	4.69	8.61	8.69	7.95	9.74	10.79	10.80	14.55	13.91	13.80
2.18	1.95	1.91	2.84	2.88	2.70	3.12	3.41	3.45	4.39	4.24	4.22
8.30	7.11	6.84	11.52	11.56	10.58	12.89	14.04	13.99	18.89	18.02	17.86
25.73	19.73	17.90	34.8	31.93	28.83	38.84	38.86	38.96	55.92	50.14	37.35
26.33	20.70	18.75	35.56	33.67	29.92	40.04	40.93	40.19	57.19	52.42	39.40
27.33	21.68	20.79	38.19	36.88	32.12	45.27	44.81	41.34	58.55	54.38	43.09
28.33	22.32	21.65	40.17	38.15	33.56	45.24	46.62	43.58	62.04	57.10	45.85
1.49	0.78	0.48	2.52	2.35	1.83	2.95	3.28	3.26	5.18	4.85	4.81
2.27	1.41	0.93	3.64	3.33	2.72	4.19	4.54	4.46	6.88	6.46	6.40
30.87	24.98	22.53	44.94	43.86	36.98	49.82	52.09	49.05	71.62	65.43	54.35
32.13	26.09	23.48	46.74	45.67	38.00	51.84	54.40	51.36	74.58	68.33	57.20
34.65	27.30	24.31	49.43	47.83	40.83	56.12	58.19	54.91	81.25	73.01	61.96
0.66	0.56	0.53	0.94	0.96	0.88	1.07	1.19	1.20	1.61	1.55	1.54
2.63	2.11	1.95	3.86	3.90	3.52	4.40	4.96	4.98	6.94	6.61	6.55
1.47	1.23	1.20	2.09	2.13	1.96	2.36	2.64	2.66	3.59	3.44	3.42
2.59	1.92	1.73	3.84	3.80	3.37	4.37	4.90	4.91	7.06	6.69	6.62
9.64	7.58	6.71	12.21	11.16	9.55	13.34	13.20	12.17	18.43	16.37	15.04
11.11	9.05	7.35	14.67	12.85	11.03	16.05	16.58	14.47	22.72	20.67	17.69
2.55	1.89	1.65	3.33	2.91	2.46	3.66	3.49	3.21	5.14	4.39	4.02
5.47	4.48	4.04	7.34	7.24	5.75	8.13	8.84	7.87	12.00	11.07	10.04
18.24	14.51	11.80	24.90	22.60	17.87	28.46	28.54	24.49	41.26	35.68	[illegible]
18.78	12.66	11.67	26.55	24.24	19.20	29.53	27.74	26.95	45.61	36.59	[illegible]
56.51	44.12	38.73	92.71	81.23	68.05	93.21	99.30	94.23	139.59	130.76	116.12

TABLE 3.8 DESIGN, DIAMETER AND PEAK DISCHARGE OF

SR. NO.	BRCH RCH.	DIAMETER IN INCHES — 2 YEARS 30 MIN	45 MIN	60 MIN	5 YEARS 30 MIN	45 MIN	60 MIN	10 YEARS 30 MIN	45 MIN	60 MIN	25 YEARS 30 MIN	45 MIN	60 MIN	2 YEARS 30 MIN	45 MIN	60 MIN
1	1-0	12	12	12	12	12	12	12	12	12	12	12	12	1.0	0.82	0.8
2	1-1	12	12	12	15	15	15	15	15	15	18	18	18	2.2	1.49	1.23
3	2-0	18	15	15	18	18	18	18	18	18	21	18	18	5.28	3.69	3.63
4	3-0	12	12	12	12	12	12	12	12	12	12	12	12	0.39	0.19	0.10
5	3-1	12	12	12	12	12	12	12	12	12	12	12	12	0.68	0.45	0.34
6	4-0	12	12	12	12	12	12	12	12	12	12	12	12	0.33	0.28	0.27
7	3-2	12	12	12	12	12	12	12	15	15	15	15	15	1.38	1.04	0.91
8	3-3	15	12	12	15	15	15	15	15	15	18	18	18	2.53	2.03	1.89
9	5-0	12	12	12	12	12	12	12	12	12	12	12	12	0.67	0.51	0.45
10	3-4	15	15	15	18	18	18	18	21	21	24	21	21	4.5	3.63	3.38
11	6-0	12	12	12	12	12	12	12	12	12	12	12	12	0.83	0.73	0.73
12	3-5	18	18	18	21	21	21	21	21	21	24	24	24	5.99	4.95	4.69
13	1-2	24	21	21	27	27	24	27	27	27	33	30	24	14.04	10.07	8.90
14	1-3	24	21	21	27	27	24	30	27	27	33	30	24	14.97	10.79	9.48
15	1-4	27	24	21	30	27	27	30	30	30	33	33	27	16.26	11.52	10.50
16	1-5	27	24	24	30	27	27	30	30	30	36	33	27	17.40	12.46	11.32
17	7-0	12	12	12	12	12	12	15	15	15	15	15	15	1.69	1.42	1.37
18	8-0	12	12	12	15	15	12	15	15	15	15	15	15	1.84	1.56	1.51
19	7-1	18	18	18	21	21	21	21	21	21	24	24	24	6.11	5.16	4.69
20	9-0	12	12	12	15	15	15	15	15	15	15	15	15	2.18	1.95	1.91
21	7-2	21	18	18	24	24	21	24	24	24	27	27	27	8.30	7.11	6.84
22	1-6	30	27	27	33	33	30	36	36	36	39	39	33	25.73	19.73	17.90
23	1-7	30	27	27	33	33	33	36	36	36	39	39	36	26.83	20.76	18.75
24	1-8	30	27	27	36	33	33	36	36	36	42	39	36	27.33	21.68	20.79
25	1-9	30	30	27	36	36	33	36	36	36	42	39	36	28.33	22.32	21.55
26	10-0	12	12	12	15	12	12	15	15	15	18	18	18	1.49	0.78	0.48
27	10-1	12	12	12	15	15	15	15	15	15	18	18	18	2.27	1.41	0.93
28	1-10	33	30	30	36	36	33	39	39	39	45	42	39	30.87	24.98	22.53
29	1-11	33	30	30	36	36	36	39	39	39	45	42	39	32.13	26.09	23.48
30	1-12	33	30	30	39	39	36	39	39	39	45	45	42	34.65	27.38	24.31
31	13-0	12	12	12	12	12	12	12	12	12	12	12	12	0.66	0.56	0.55
32	13-1	15	12	12	15	15	15	15	18	18	18	18	18	2.63	2.11	1.95
33	14-0	12	12	12	12	12	12	12	15	15	15	15	15	1.47	1.23	1.20
34	14-1	15	12	12	15	15	15	15	18	18	18	18	18	2.59	1.92	1.73
35	14-2	21	21	18	24	21	21	24	24	24	27	27	24	9.54	7.58	6.71
36	14-3	21	21	18	24	24	21	27	27	24	30	27	27	11.11	9.05	7.35
37	15-0	15	12	12	15	15	12	15	15	15	18	15	15	2.55	1.89	1.65
38	15-1	18	15	15	18	18	18	21	21	21	24	21	21	5.47	4.48	4.04
39	14-4	27	24	24	30	30	27	30	30	30	36	33	33	18.24	14.51	11.80
40	14-5	27	24	24	30	30	27	33	30	30	36	33	33	18.78	12.66	11.67
41	1-13	39	36	36	45	45	42	48	48	48	57	54	51	56.51	44.12	38.73

TABLE 3.9. DESIGN DIAMETER AND PEAK DISCHARGE OF SUB-SYSTEM IV, OF I.I.T. KANPUR.

SR. NO.	BRCH-RCH.	DIAMETER IN INCHES												DESIGN DISCHARGE IN C.F.S.											
		2 YEARS			5 YEARS			10 YEARS			25 YEARS			2 YEARS			5 YEARS			10 YEARS			25 YEARS		
		30 MIN.	45 MIN.	60 MIN.	30 MIN.	45 MIN.	60 MIN.	30 MIN.	45 MIN.	60 MIN.	30 MIN.	45 MIN.	60 MIN.	30 MIN.	45 MIN.	60 MIN.	30 MIN.	45 MIN.	60 MIN.	30 MIN.	45 MIN.	60 MIN.	30 MIN.	45 MIN.	60 MIN.
1	1-0	12	12	12	12	12	12	12	12	12	12	12	12	.94	0.76	0.69	1.23	1.16	0.97	1.35	1.39	1.3	1.90	1.74	1.50
2	2-0	12	12	12	12	12	12	12	12	12	12	12	12	1.27	0.94	0.78	1.74	1.55	1.20	1.94	1.9	1.80	2.84	2.44	2.16
3	1-1	12	12	12	15	12	12	15	15	12	15	15	15	2.79	2.06	1.73	3.78	3.33	2.66	4.19	4.08	3.89	6.05	5.18	4.62
4	3-0	12	12	12	12	12	12	12	12	12	12	12	12	0.69	0.53	0.41	0.96	0.88	0.68	1.07	1.08	1.06	1.58	1.39	1.25
5	4-0	12	12	12	12	12	12	12	12	12	12	12	12	0.75	0.59	0.47	1.02	0.94	0.76	1.13	1.14	1.10	1.64	1.45	1.34
6	1-2	15	12	12	18	15	15	18	18	15	21	18	18	4.80	3.42	2.94	6.58	5.62	4.70	7.32	6.95	6.35	10.61	8.94	8.14
7	5-0	12	12	12	15	15	12	15	15	12	15	15	15	3.44	2.70	2.58	4.34	3.73	3.35	4.72	4.32	4.03	6.45	5.24	4.97
8	1-3	18	18	15	21	21	18	21	21	18	24	24	21	8.97	7.10	6.10	11.89	10.85	8.54	13.10	13.07	12.84	18.46	16.39	14.23
9	6-0	12	12	12	12	12	12	12	12	12	12	12	12	0.74	0.60	0.48	1.01	0.95	0.76	1.12	1.15	1.11	1.63	1.47	1.34
10	7-0	12	12	12	12	12	12	12	12	12	12	12	12	0.74	0.60	0.48	1.41	0.95	0.76	1.12	1.15	1.11	1.65	1.47	1.34
11	8-0	15	12	12	15	15	15	15	15	12	18	18	15	3.92	3.24	3.05	5.02	4.65	4.03	5.49	5.45	5.39	7.58	6.73	6.22
12	1-4	21	21	21	24	24	21	27	27	24	30	27	27	15.61	12.49	10.70	20.60	18.73	15.07	22.63	22.65	21.30	31.86	28.39	24.55
13	9-0	12	12	12	12	12	12	12	12	12	12	12	12	0.83	0.63	0.50	1.14	1.04	0.86	1.27	1.27	1.27	1.87	1.63	1.54
14	10-0	12	12	12	12	12	12	12	12	12	12	12	12	0.57	0.46	0.42	0.79	0.75	0.59	0.88	0.92	0.78	1.30	1.18	1.03
15	1-5	24	21	21	27	24	24	27	27	24	30	30	27	18.62	14.60	12.15	25.04	22.28	17.87	28.04	26.85	24.05	39.61	33.55	28.60
16	11-0	12	12	12	12	12	12	12	12	12	12	12	12	0.89	0.72	0.65	1.25	1.19	0.92	1.40	1.46	1.41	2.08	1.88	1.64
17	1-6	27	24	21	27	27	24	30	30	24	33	30	30	22.79	17.22	14.99	30.71	26.29	21.59	34.12	32.25	28.54	48.03	46.73	35.25
18	12-0	12	12	12	12	12	12	12	12	12	12	12	12	1.01	0.67	0.66	1.60	1.00	0.88	1.43	1.20	1.10	2.00	1.50	1.41
19	12-1	12	12	12	12	12	12	12	12	12	15	15	12	1.89	1.56	1.35	2.59	2.53	2.02	2.89	3.08	2.70	4.24	3.94	3.45
20	12-2	15	12	12	15	15	12	16	15	12	18	18	15	3.64	2.80	2.35	4.96	4.57	3.50	5.50	5.49	5.10	8.06	7.07	5.96
21	13-0	12	12	12	12	12	12	12	12	12	12	12	12	1.22	0.95	0.73	1.73	1.61	1.23	1.95	2.0	1.89	2.92	2.60	2.33
22	13-1	12	12	12	12	12	12	12	12	12	15	15	15	2.18	1.62	1.29	3.45	2.78	2.45	3.41	3.44	3.30	5.04	4.45	3.94
23	14-0	12	12	12	15	15	12	15	15	12	18	15	15	[illegible]	2.18	2.14	4.69	3.76	3.03	5.21	4.68	4.21	7.55	6.13	5.52
24	15-0	12	12	12	12	12	12	12	12	12	12	12	12	0.38	0.22	0.16	0.61	0.58	0.48	0.71	0.79	0.7	1.25	1.19	1.27
25	13-2	18	15	15	18	18	18	21	21	18	24	21	21	6.95	4.99	4.12	9.91	8.70	6.36	11.07	10.85	9.35	15.89	14.09	12.22
26	16-0	12	12	12	15	15	12	15	15	12	18	15	15	3.30	2.22	2.11	4.45	3.80	3.07	4.95	4.89	4.01	7.12	6.08	5.46
27	13-3	21	18	18	24	21	21	24	24	21	27	27	24	12.25	8.94	7.53	16.98	15.13	11.15	19.34	18.79	17.59	25.05	24.06	20.87
28	17-0	12	12	12	12	12	12	12	12	12	12	12	12	0.84	0.57	0.46	1.14	1.05	0.80	1.27	1.25	1.20	1.84	1.65	1.45
29	18-0	12	12	12	15	12	12	15	15	12	15	15	15	2.18	2.20	1.96	3.78	3.49	2.73	4.21	4.24	3.98	[illegible]	5.41	4.57
30	19-0	12	12	12	12	12	12	12	12	12	12	12	12	0.43	0.28	0.23	0.67	0.66	0.56	0.78	.88	0.74	1.37	1.34	1.43
31	13-4	24	21	18	27	24	21	27	27	24	30	30	27	16.92	11.74	9.77	22.74	17.53	14.70	25.55	24.47	23.59	[illegible]	31.44	27.19
32	1-7	33	27	27	36	33	33	39	36	36	42	39	39	43.88	30.91	28.30	59.53	49.52	41.80	67.05	61.55	58.59	[illegible]	[illegible]	73.57
33	20-0	12	12	12	12	12	12	12	12	12	12	12	12	0.33	0.20	0.12	0.54	0.42	0.32	0.63	.57	.60	1.05	0.76	[illegible]
[illegible]	1-8	33	30	27	36	33	33	37	39	36	42	39	39	43.88	37.02	28.95	59.27	50.25	43.56	67.40	61.34	58.98	[illegible]	[illegible]	[illegible]

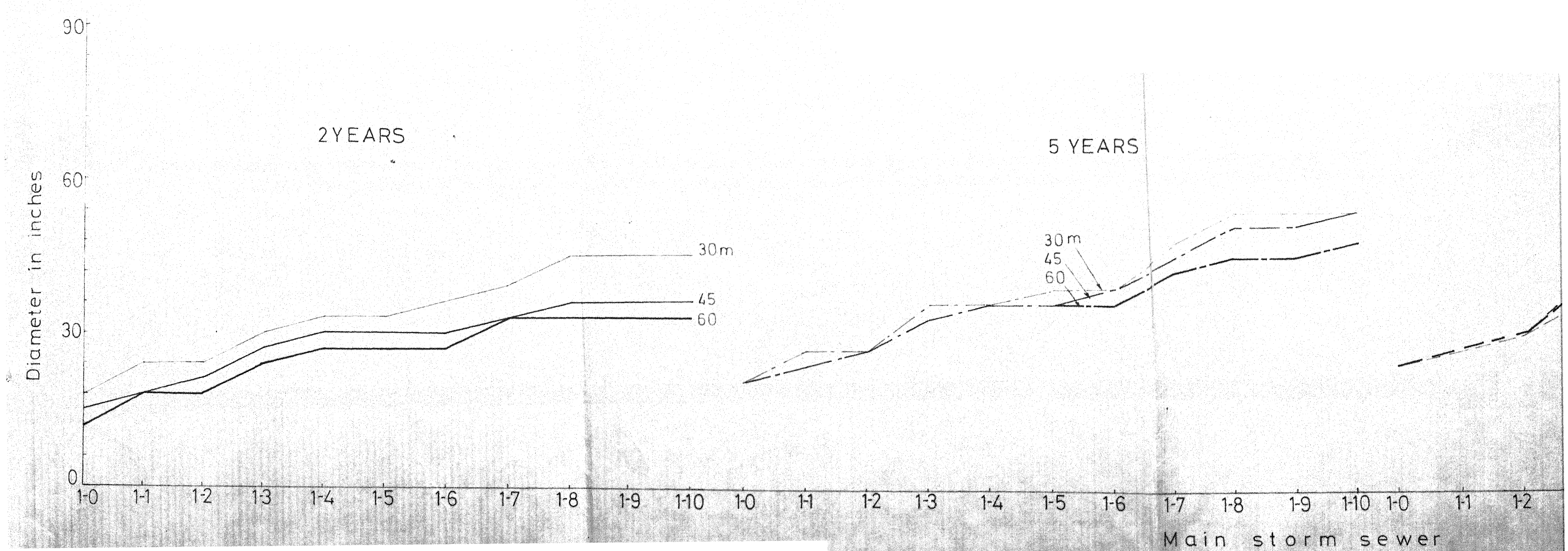
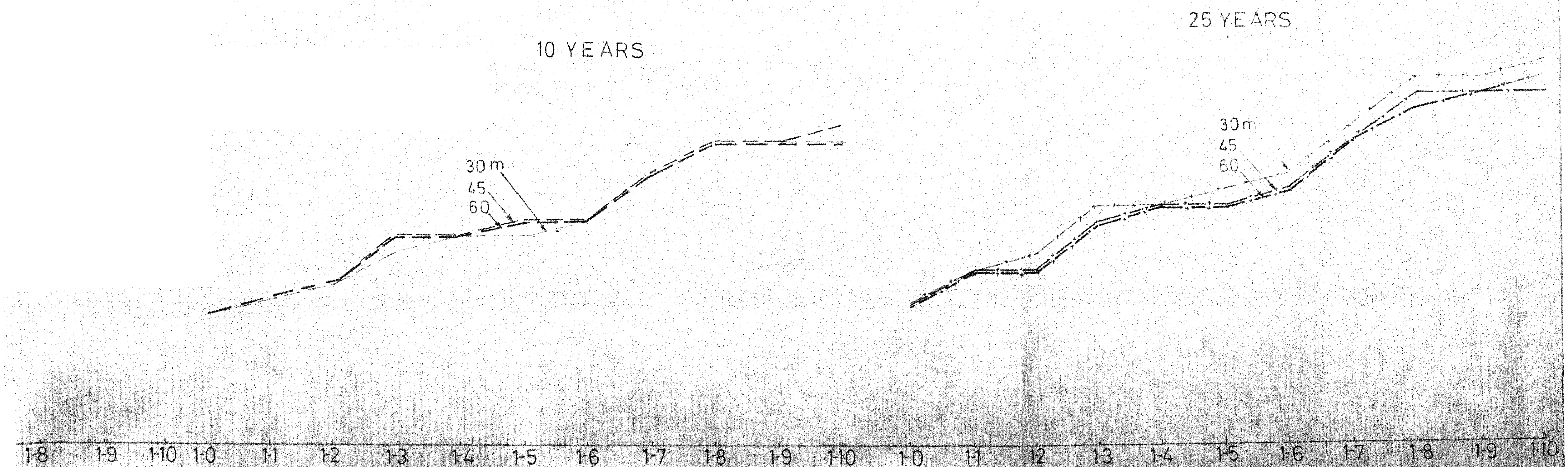


FIG. 3.7A DESIGN DIAMETER FOR SUBSYSTEM I OF I.I.T. K



storm sewer

FOR SUBSYSTEM I OF I.I.T. KANPUR

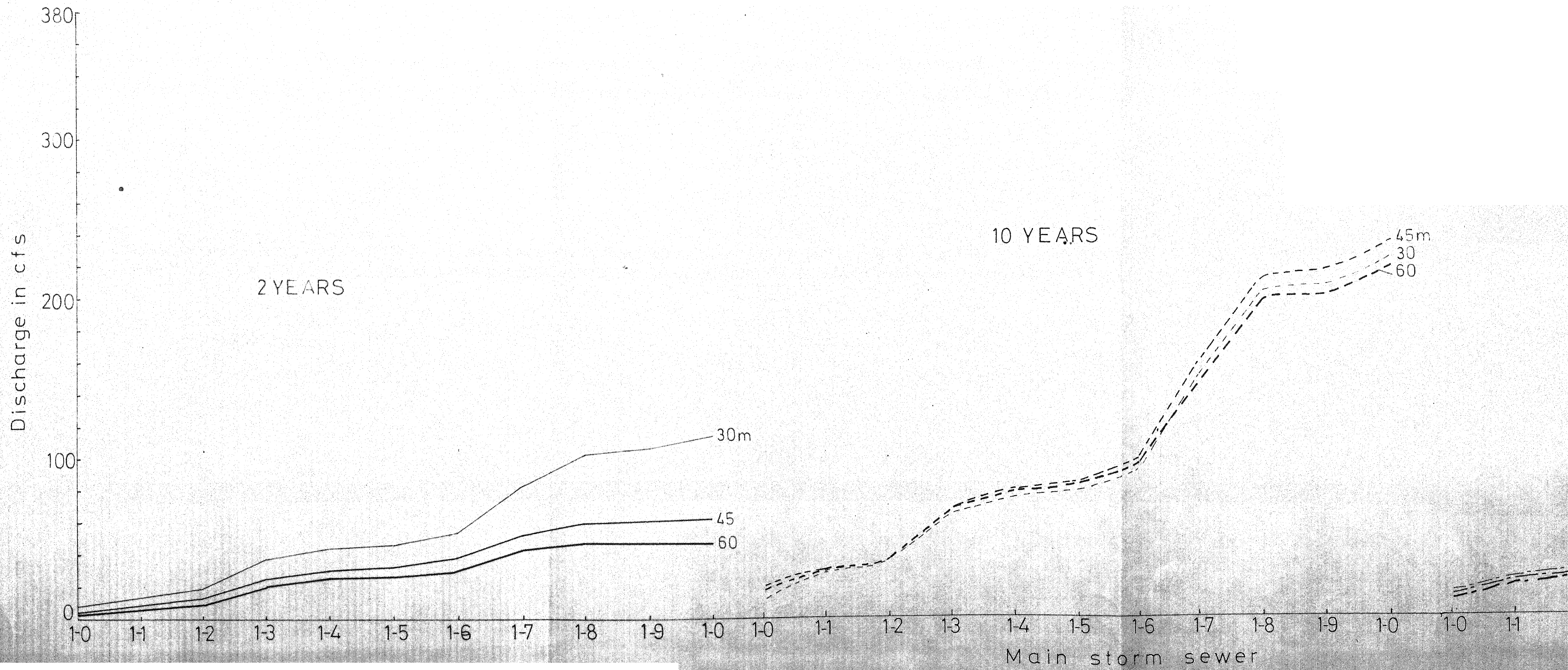
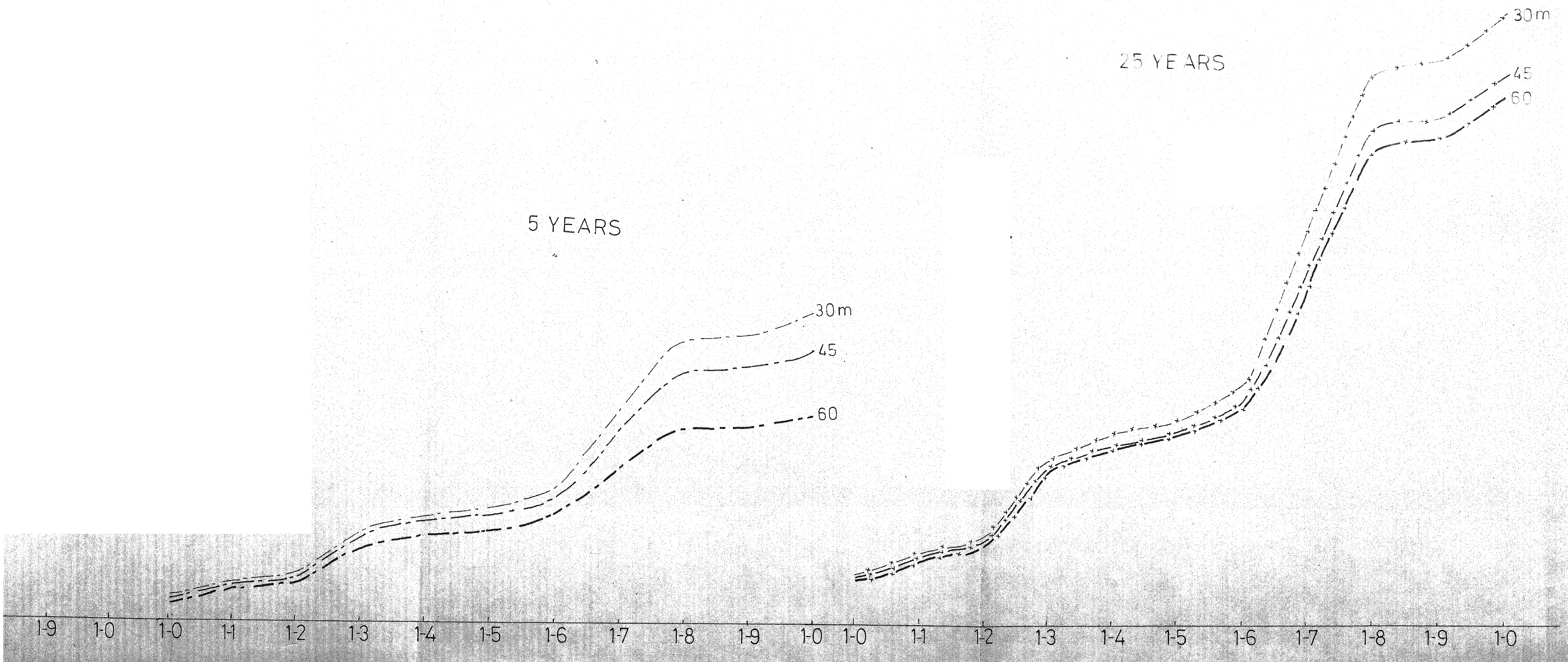


FIG. 3.7B DESIGN DISCHARGE FOR SUBSYSTEM I OF I.I.T. KANPUR



OF I.I.T. KANPUR

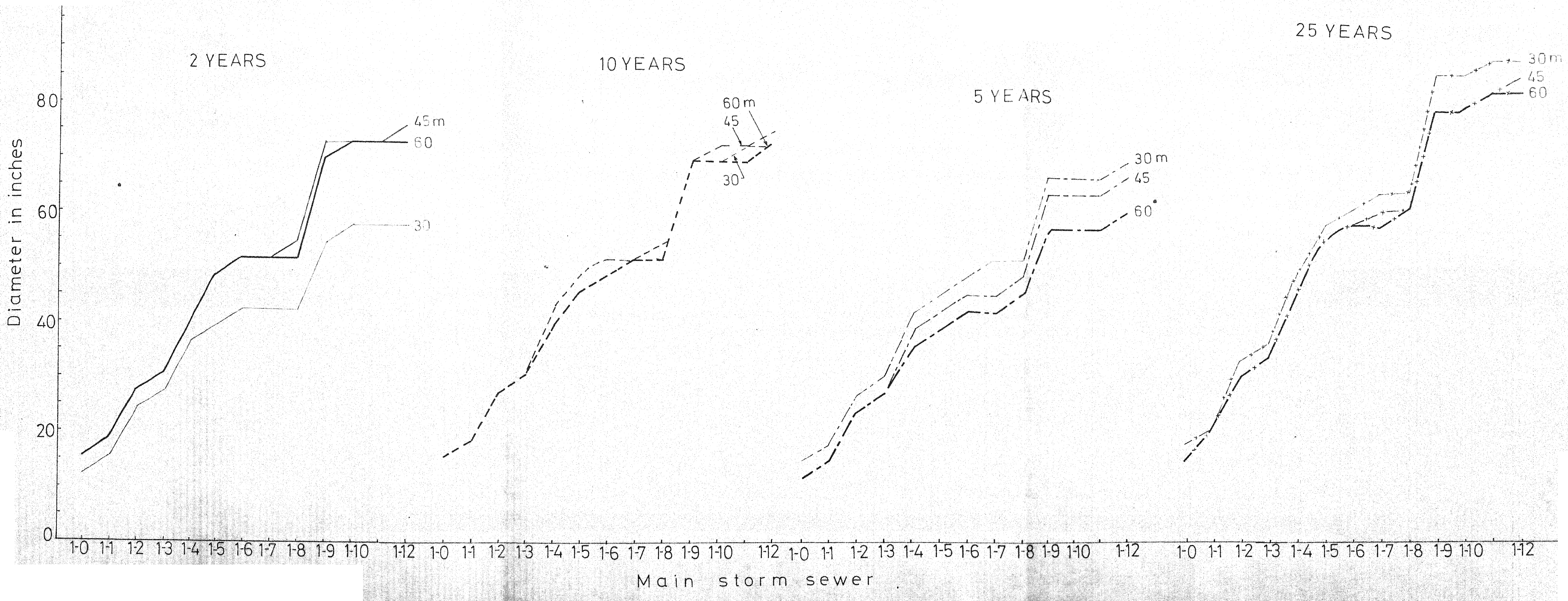


FIG. 3·8A DESIGN DIAMETER FOR SUBSYSTEM II OF I.I.T. KANPUR

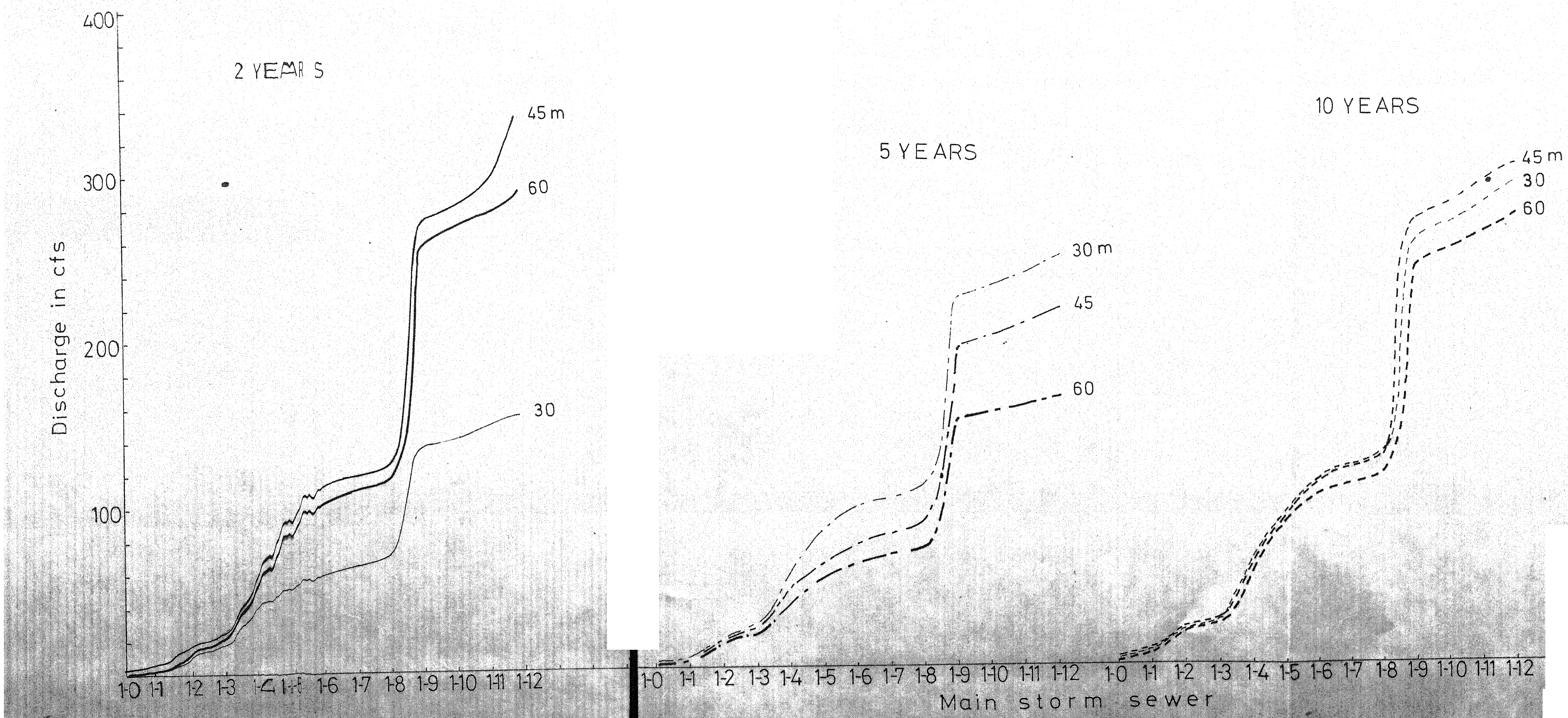
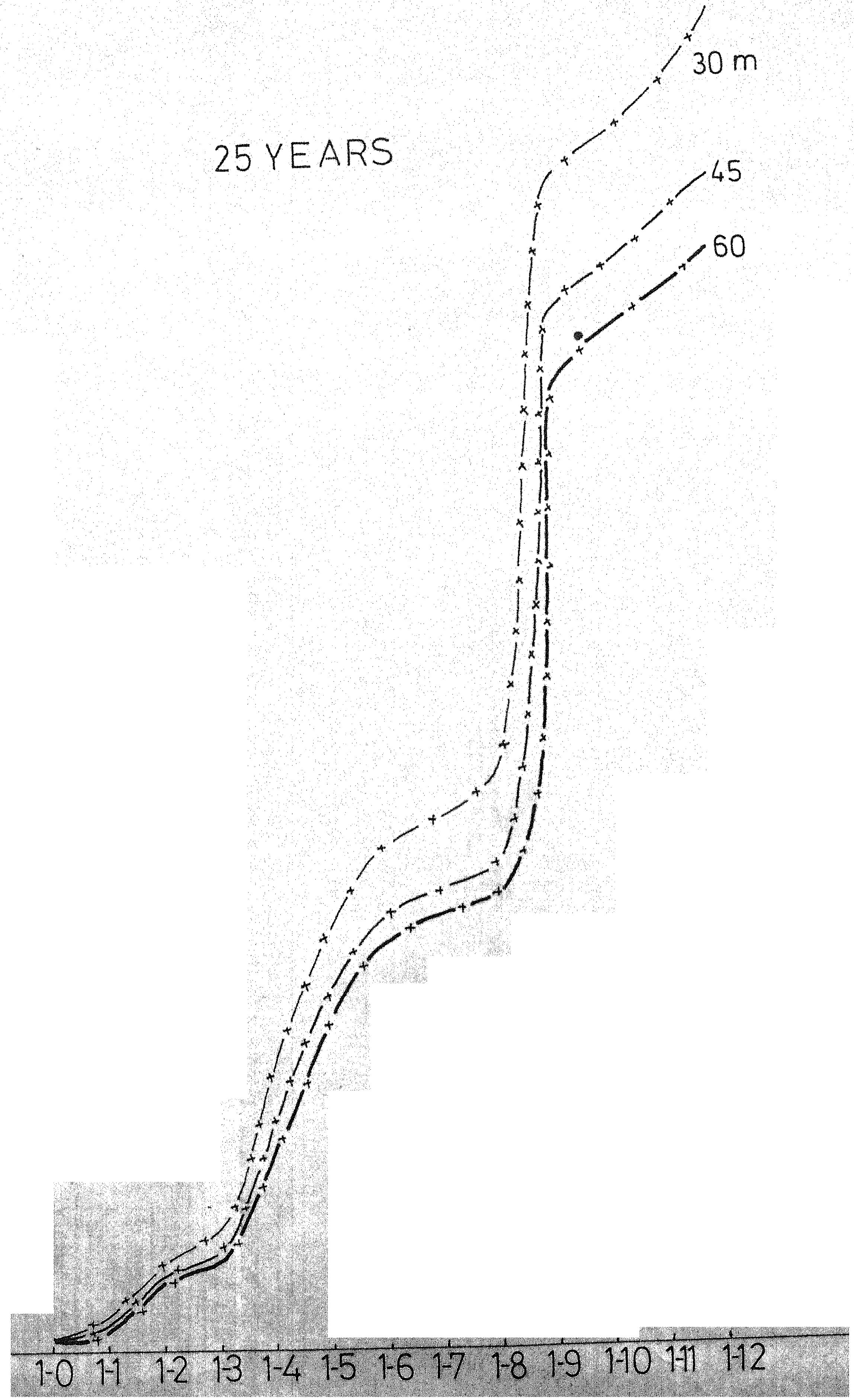


FIG 38 B DESIGN DISCHARGE FOR SUBSYSTEM II OF I.I.T. KANPUR



25 YEARS
30 m
45
60
1·0
1·1
1·2
1·3
1·4
1·5
1·6
1·7
1·8
1·9
1·10
1·11
1·12

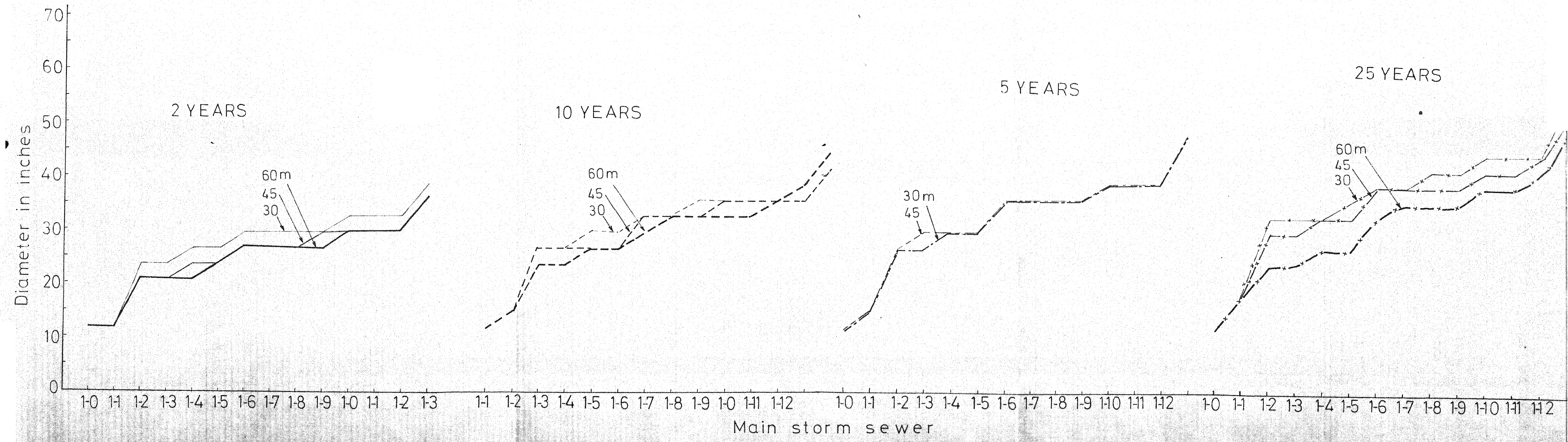


FIG.3.9A DESIGN DIAMETER FOR SUBSYSTEM III OF I.I.T. KANPUR

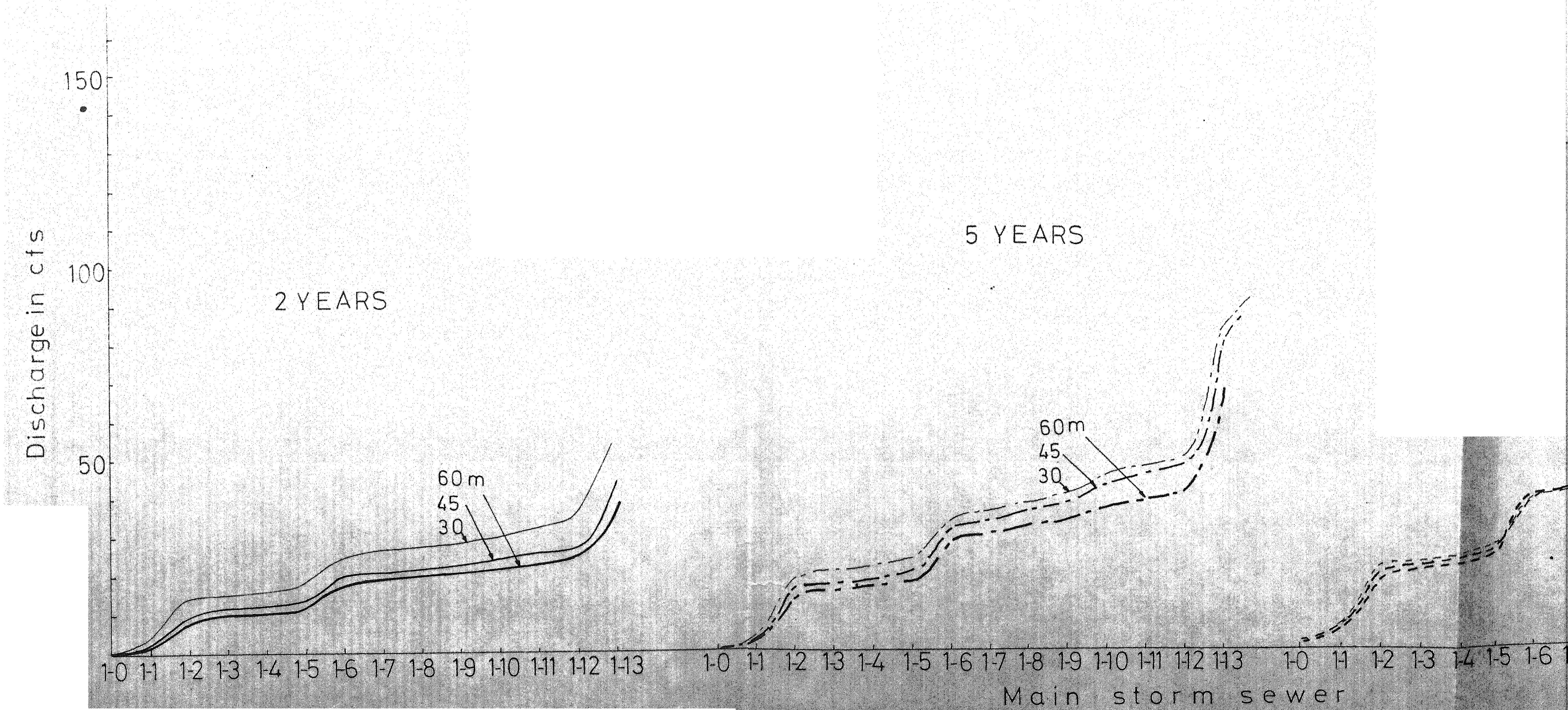
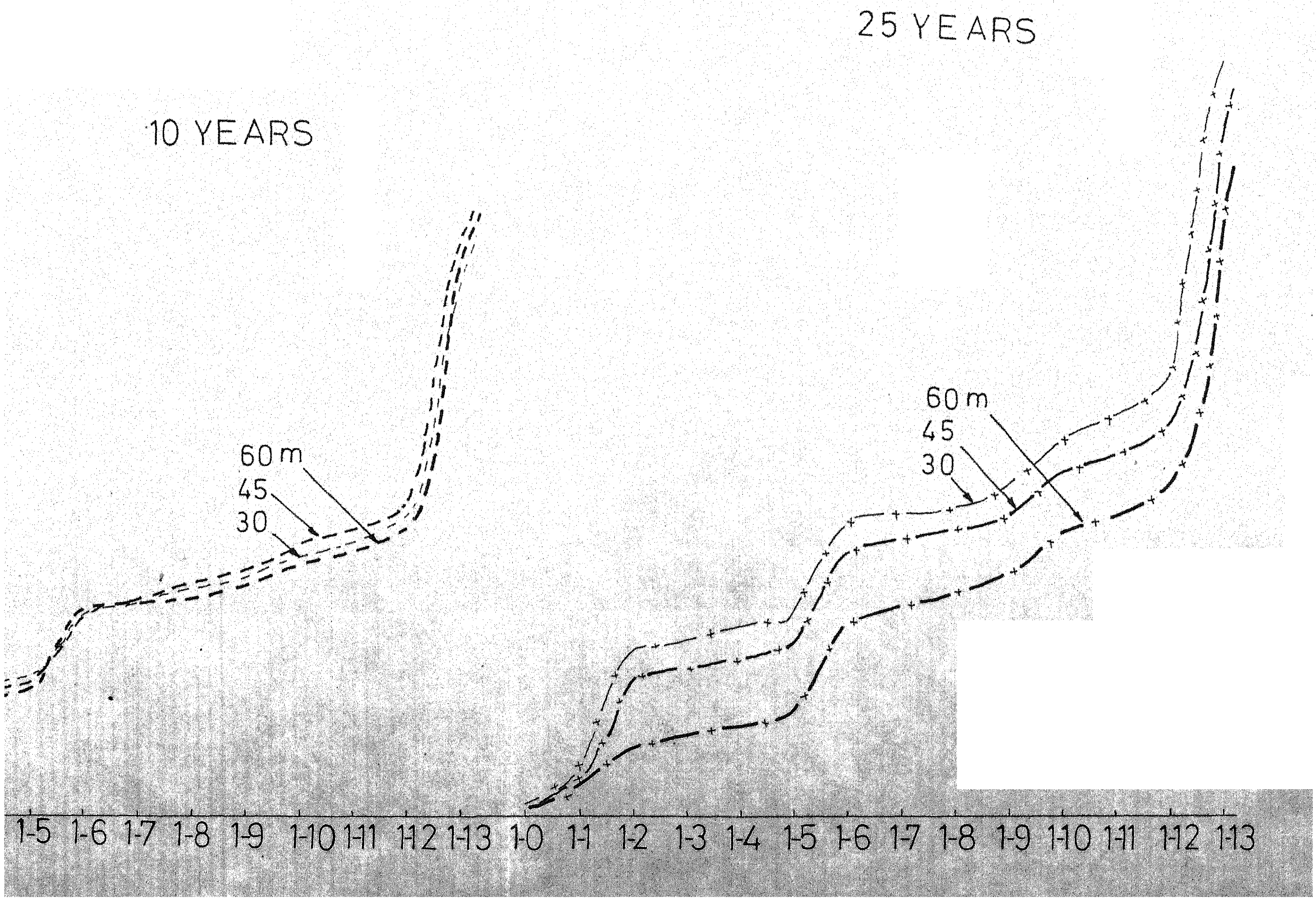


FIG. 3.9 B DESIGN DISCHARGE FOR SUBSYSTEM OF I.I.T. K


10 YEARS
25 YEARS
60 m
45
30
60 m
45
30
1-5 1-6 1-7 1-8 1-9 1-10 1-11 1-12 1-13 1-0 1-1 1-2 1-3 1-4 1-5 1-6 1-7 1-8 1-9 1-10 1-11 1-12 1-13

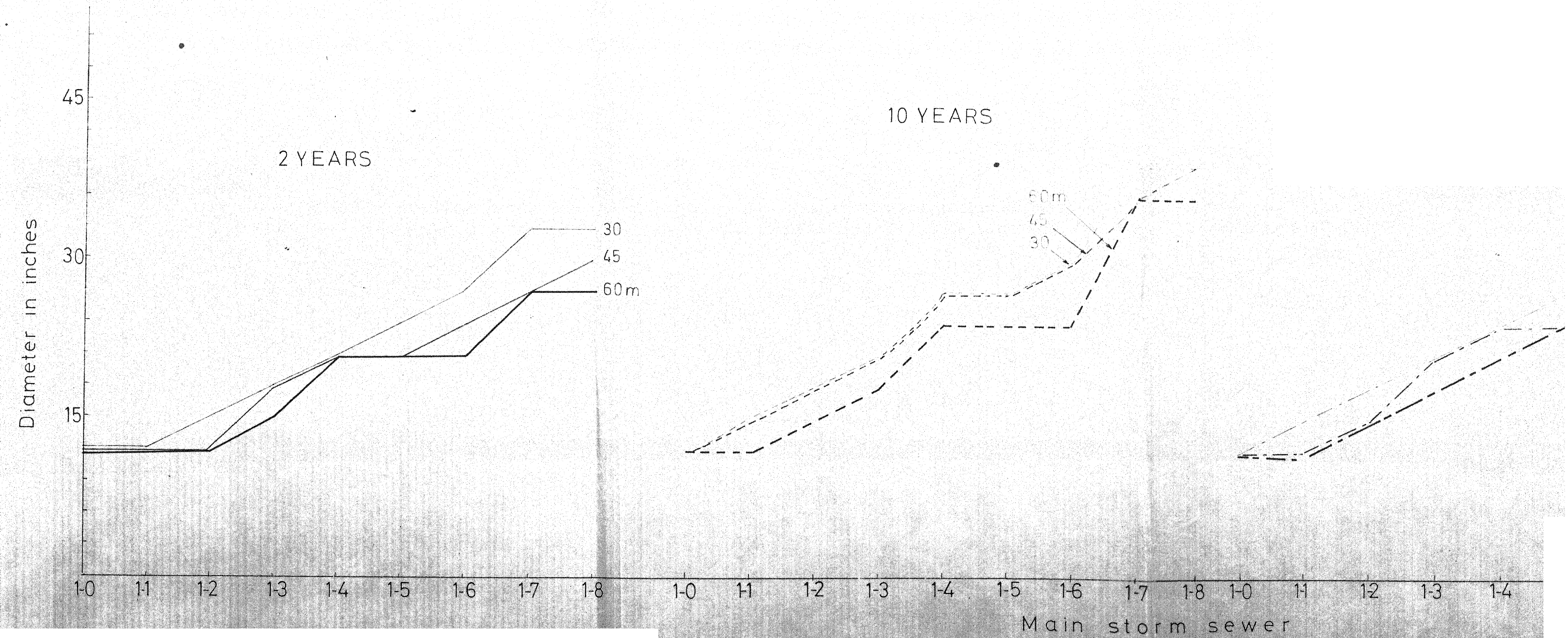
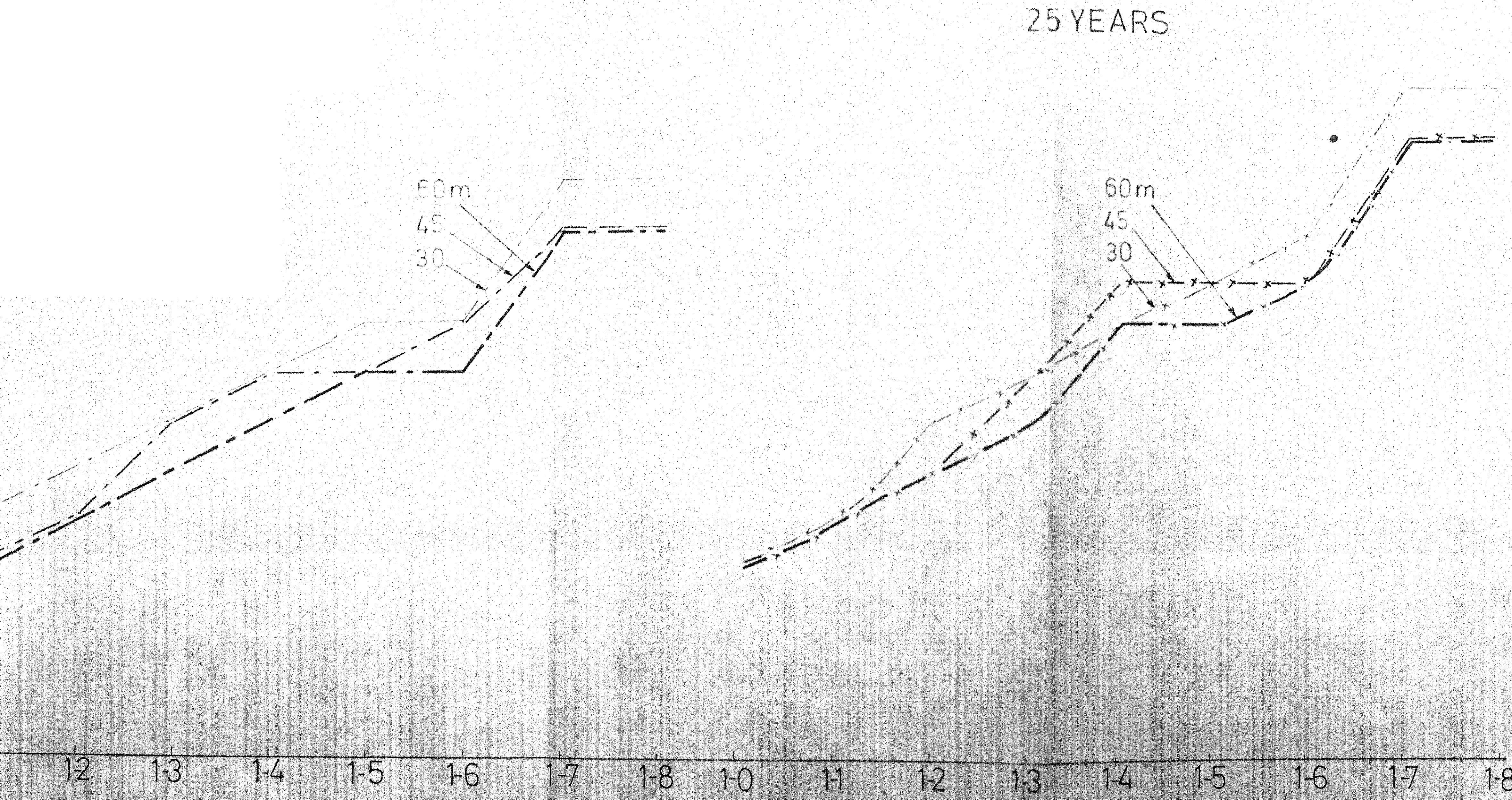


FIG. 3.10 A DESIGN DIAMETER FOR SUBSYSTEM IV OF IIT KANPUR



25 YEARS
60m
45
30
60m
45
30
1·2
1·3
1·4
1·5
1·6
1·7
1·8
1·0
1·1
1·2
1·3
1·4
1·5
1·6
1·7
1·8

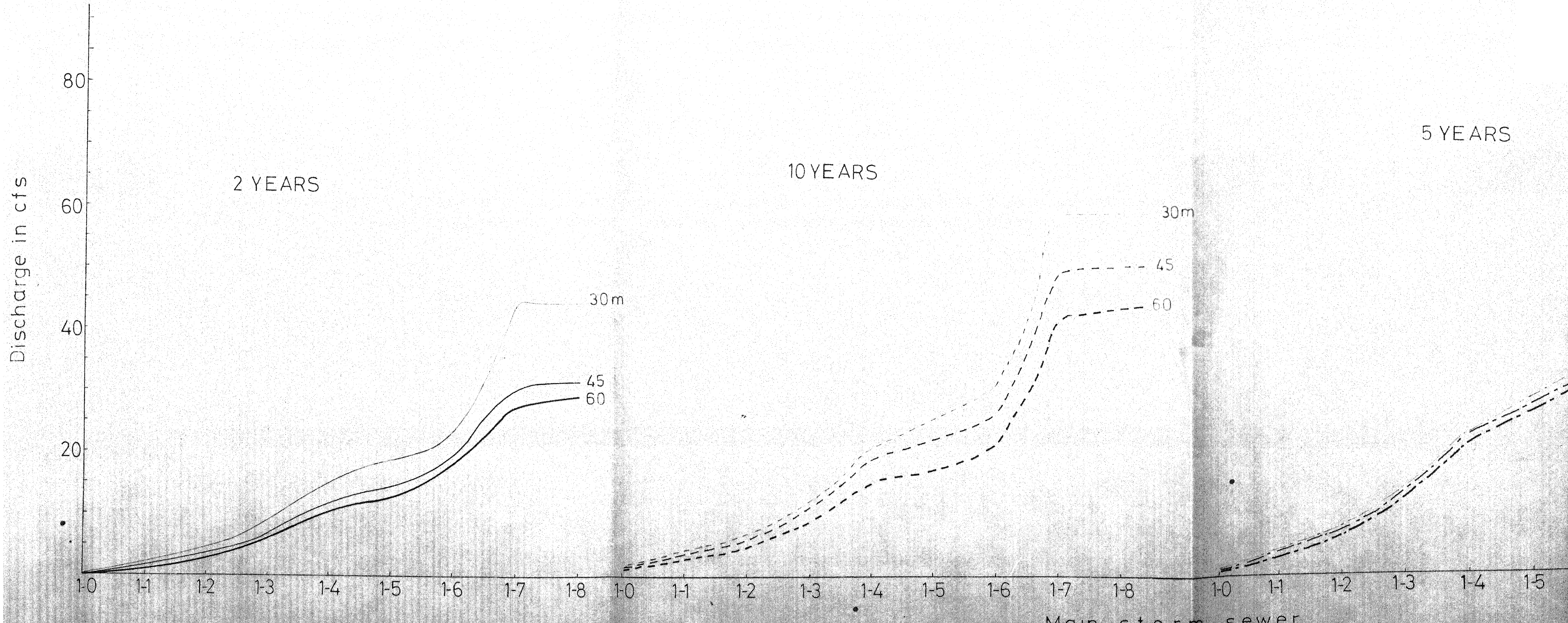
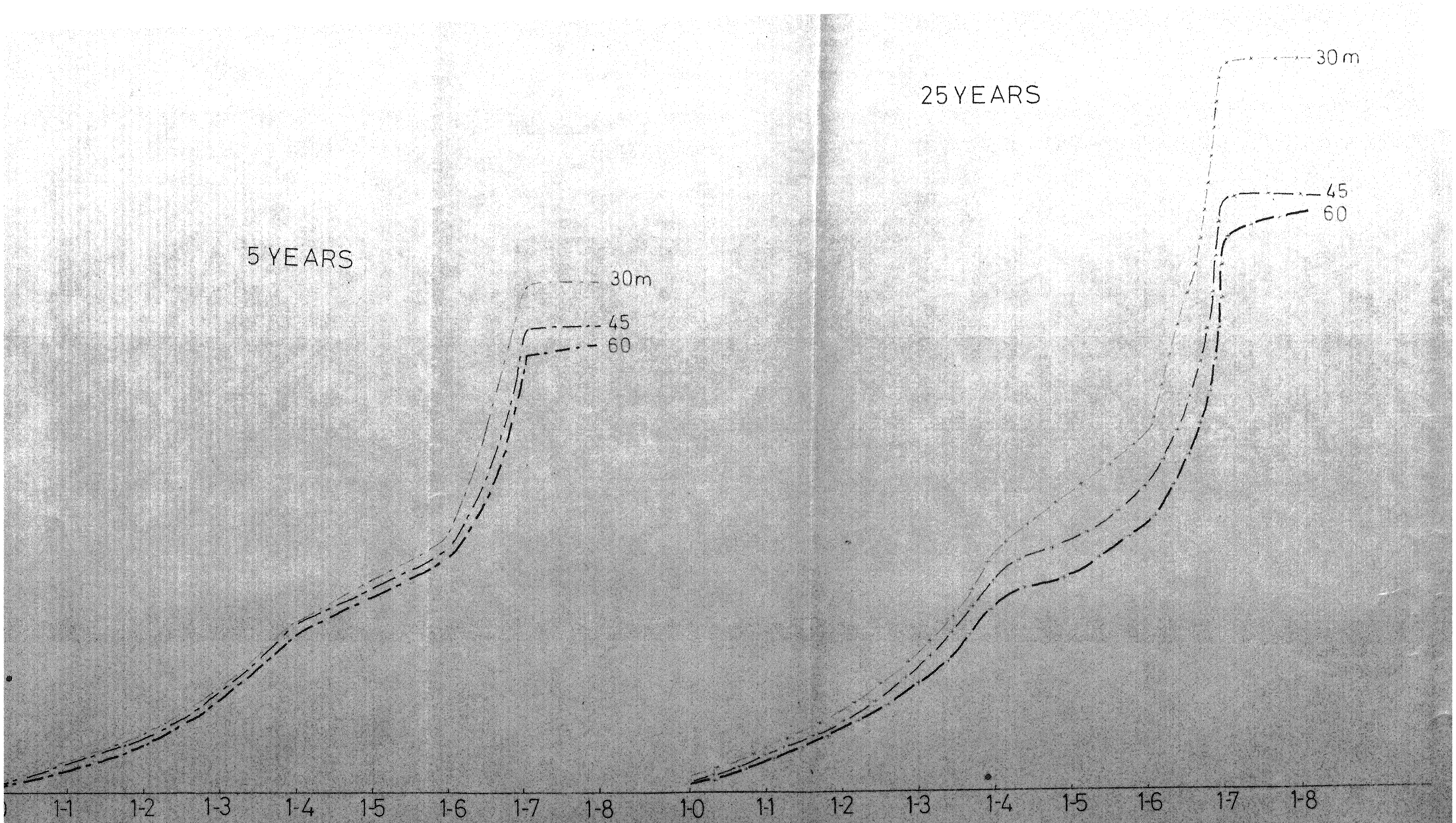


FIG 3.10B DESIGN DISCHARGE FOR SUBSYSTEM III OF IIT KANPUR



sewer

SYSTEM III OF IIT KANPUR

II, III and IV respectively. The characteristics of flow, time to peak and accumulated runoff in cubic feet for different frequencies and durations are shown in Table 3.10 for all subsystems. The hydrograph as well as accumulated runoff for the outfalls of subsystems I to IV are shown respectively in Fig.3.11, 3.12, 3.13 and 3.14.

3.6 Discussion of Results

The time to peak runoff in all the subsystems for all frequencies and durations varies between 15 and 20 minutes. Since the time distribution of storm rainfall assumes a leading pattern with 2/3 of total precipitation occuring in one third of the duration of storm, it is generally seen that the 30 minutes and in few cases 45 minutes storm, results in the peak discharge at the outfall. It is possible that for some of the upper reaches a shorter duration say 15 minutes may be more appropriate. But since in these cases the diameter is often given by the minimum specified values of 12 inches, the consideration of a 15 minutes storm may not be very necessary.

The study considers the entire grassed area to be contributing but also assumes a grassed inlet time of 20 minutes which is more than the time to peak. Furthermore the assumption of soil type B with moderate

TABLE 3.10 TIME TO PEAK, PEAK FLOW AND ACCUMULATED RUNOFF AT OUTFALL

For Subsystem I

Frequency in years	Time to peak in minutes			Peak Discharge in cfs			Accamulated runoff in 10000 cft		
	30 Min.	45 Min.	60 Min.	30 Min.	45 Min.	60 Min.	30 Min.	45 Min.	60 Min.
1	2	3	4	5	6	7	8	9	10
2	15	15	20	114.1	61.0	45.7	13.6	8.0	7.1
5	15	15	20	193.0	171.8	126.9	23.3	21.7	18.0
10	15	15	20	226.2	237.1	221.1	27.6	30.8	30.9
25	15	15	20	385.4	243.3	325.8	47.7	45.6	46.8
For Subsystem II									
2	15	20	25	151.2	304.4	284.5	18.5	42.9	44.3
5	15	20	20	248.3	206.7	164.1	30.2	28.3	25.0
10	15	20	20	286.00	293.1	271.3	35.3	39.7	40.2
25	15	20	20	475.20	413.9	388.1	88.9	56.9	58.6

Contd......

Table 3.10 contd...

For subsystem III

1	2	3	4	5	6	7	8	9	10
2	15	15	20	56.51	43.6	37.4	-	6.10	6.12
5	15	15	20	83.20	80.5	66.3	10.81	11.31	10.74
0	15	15	20	95.10	97.9	92.8	12.28	14.47	15.20
25	15	15	20	139.59	130.3	113.9	-	19.20	18.87
				For subsystem IV					
2	15	15	15	38.00	32.6	39.2	7.86	5.07	4.69
5	15	15	15	52.50	51.5	44.7	13.16	12.48	9.49
10	15	15	15	64.60	62.7	58.98	15.41	17.25	15.89
25	15	15	15	86.90	80.5	77.8	26.13	25.05	25.73

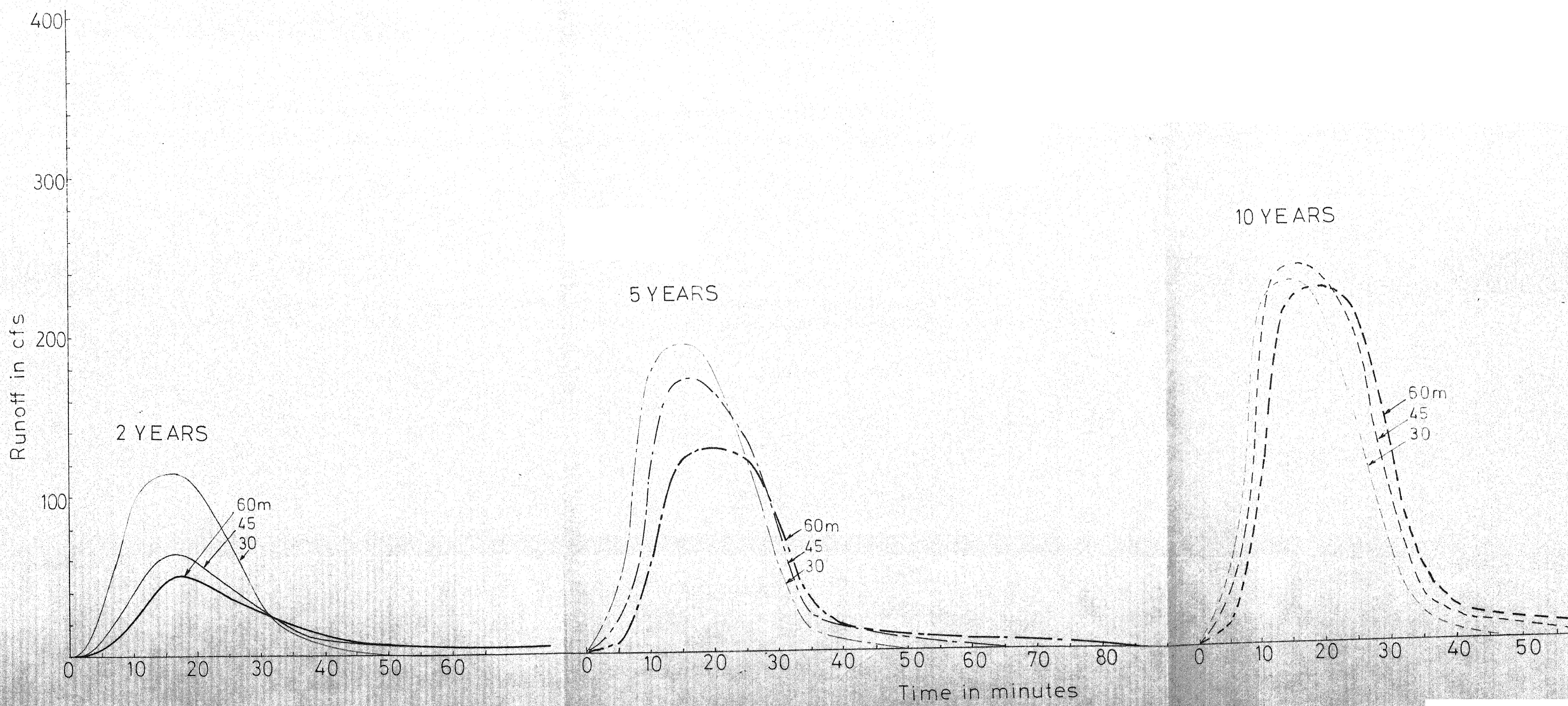
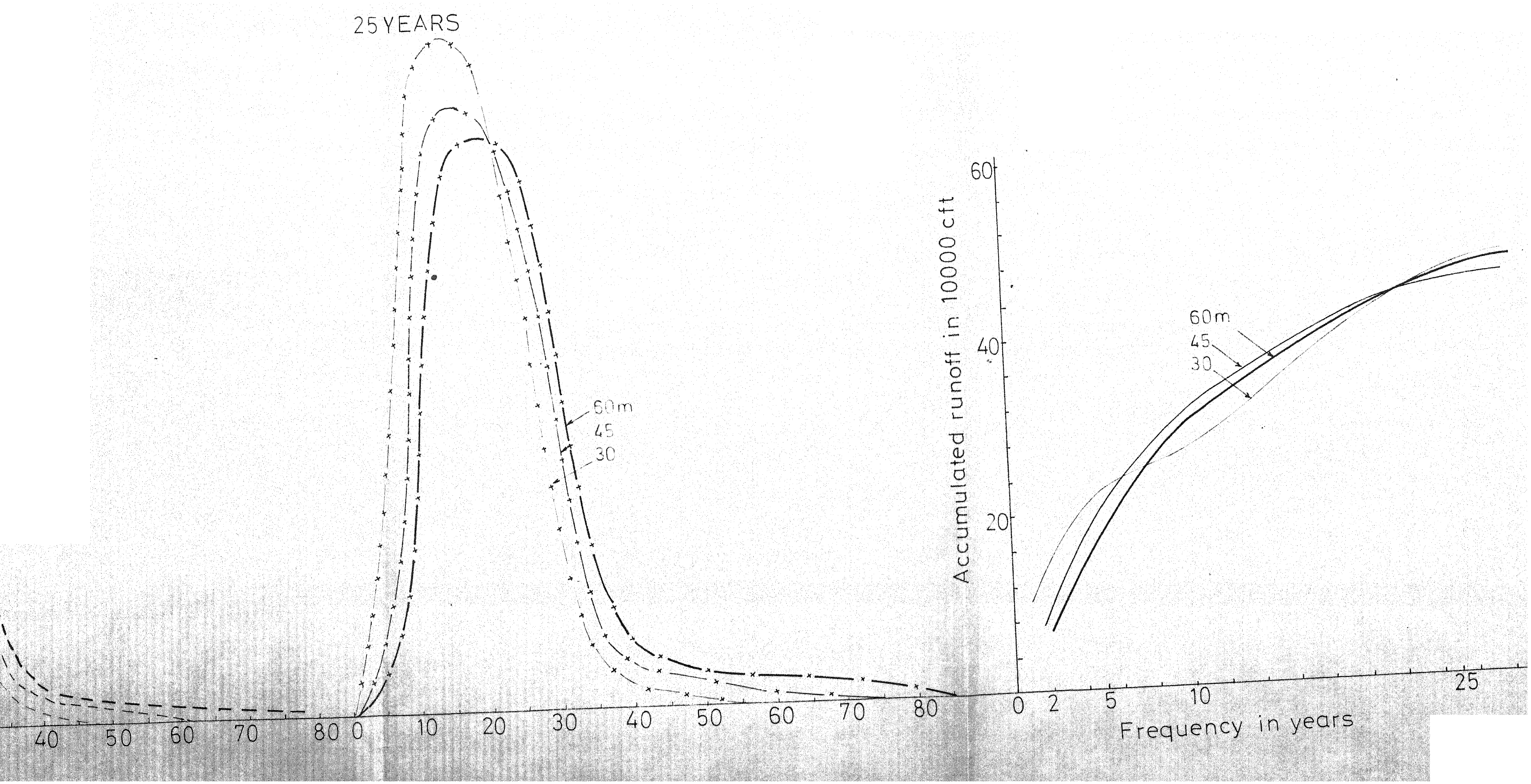


FIG.3.11 ACCUMULATED RUNOFF AND OUTFALL HYDROGRAPHS



25 YEARS
60m
45
30
40
50
60
70
80
0
10
20
30
40
50
60
70
80
Accumulated runoff in 10000 cft
60
40
20
0
2
5
10
25
Frequency in years

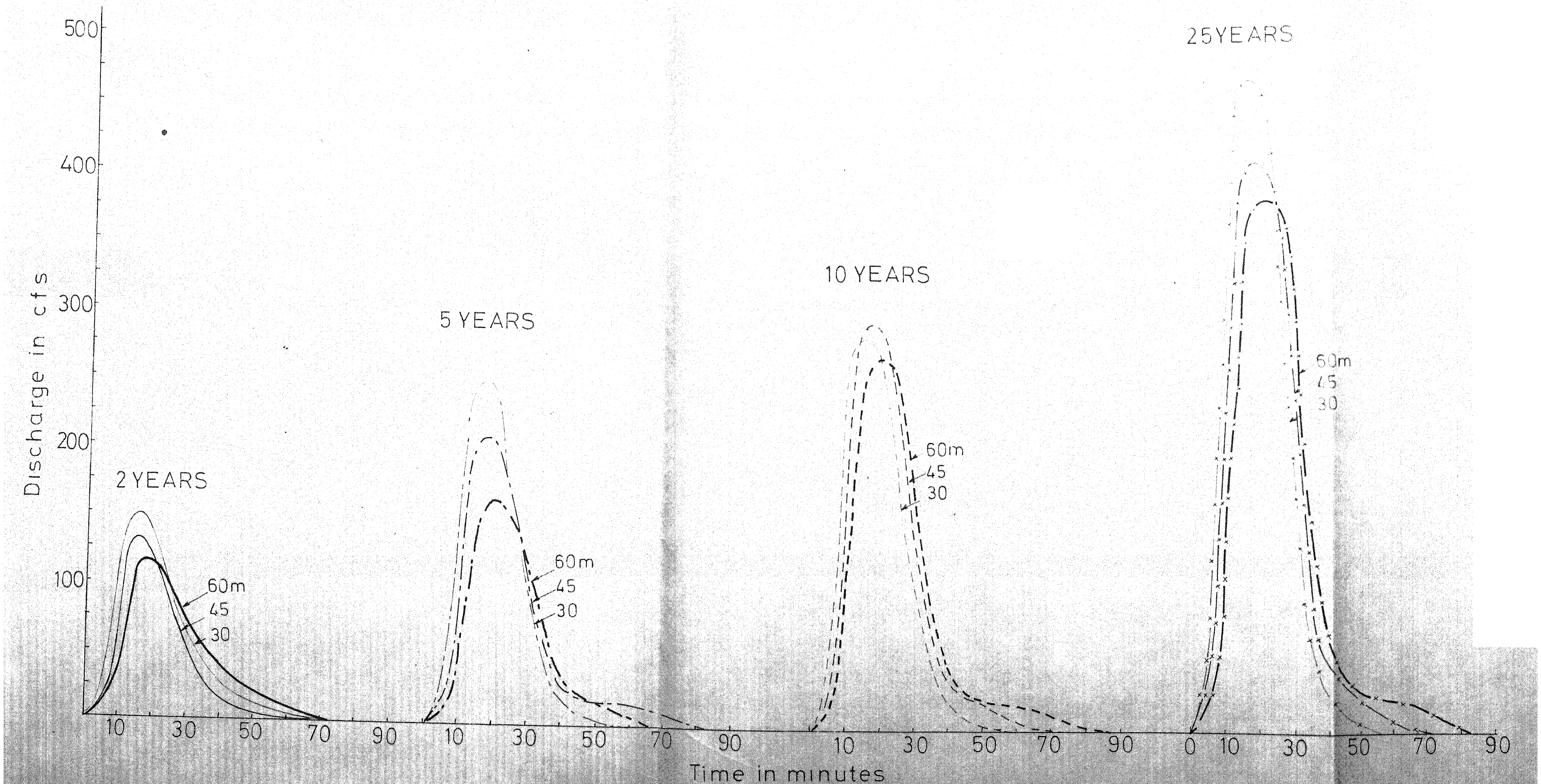
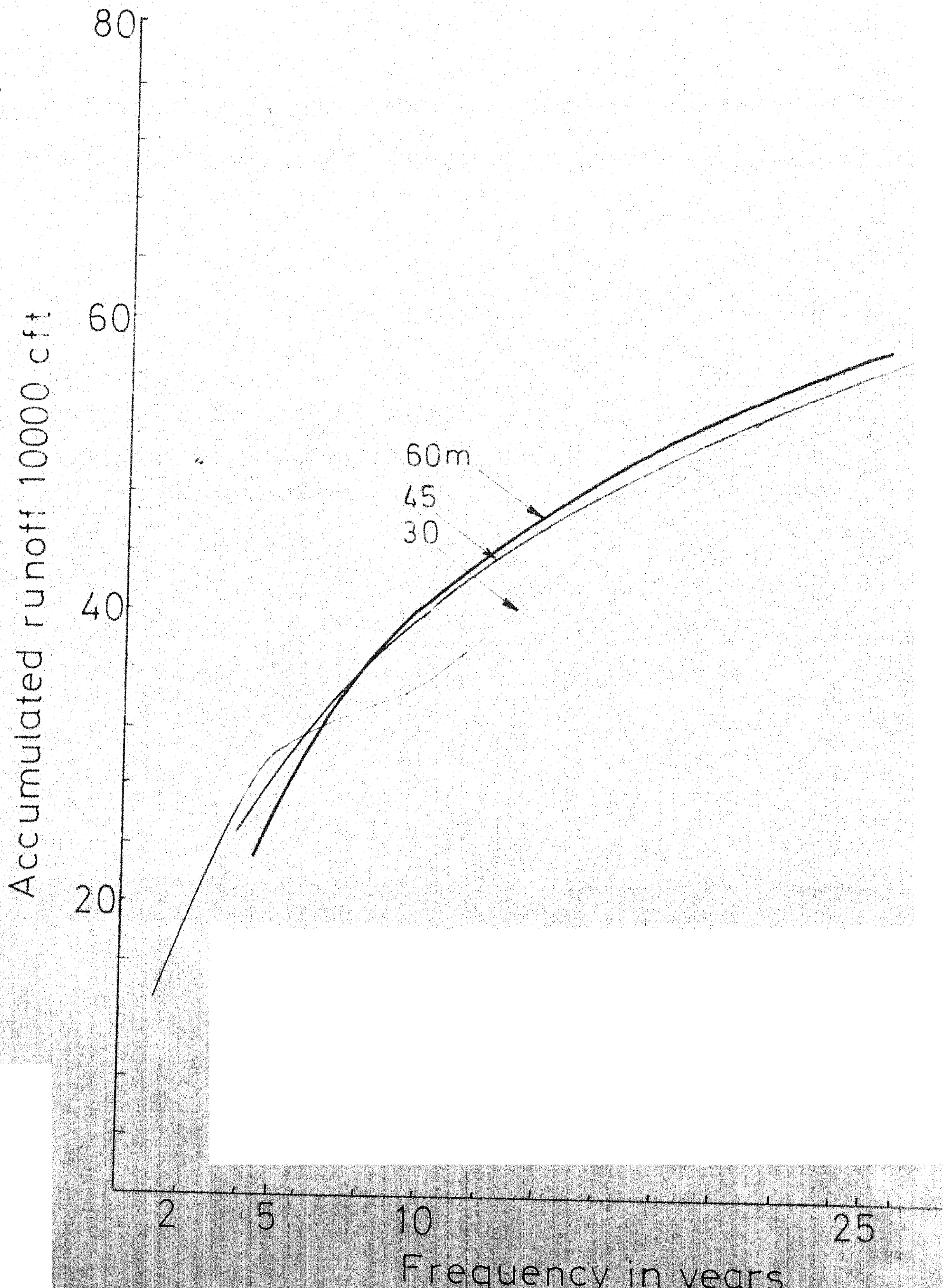


FIG. 3.12 Accumulated runoff and outfall hydrographs


80
60
40
20
Accumulated runoff 10000 cft
60m
45
30
2
5
10
25
Frequency in years

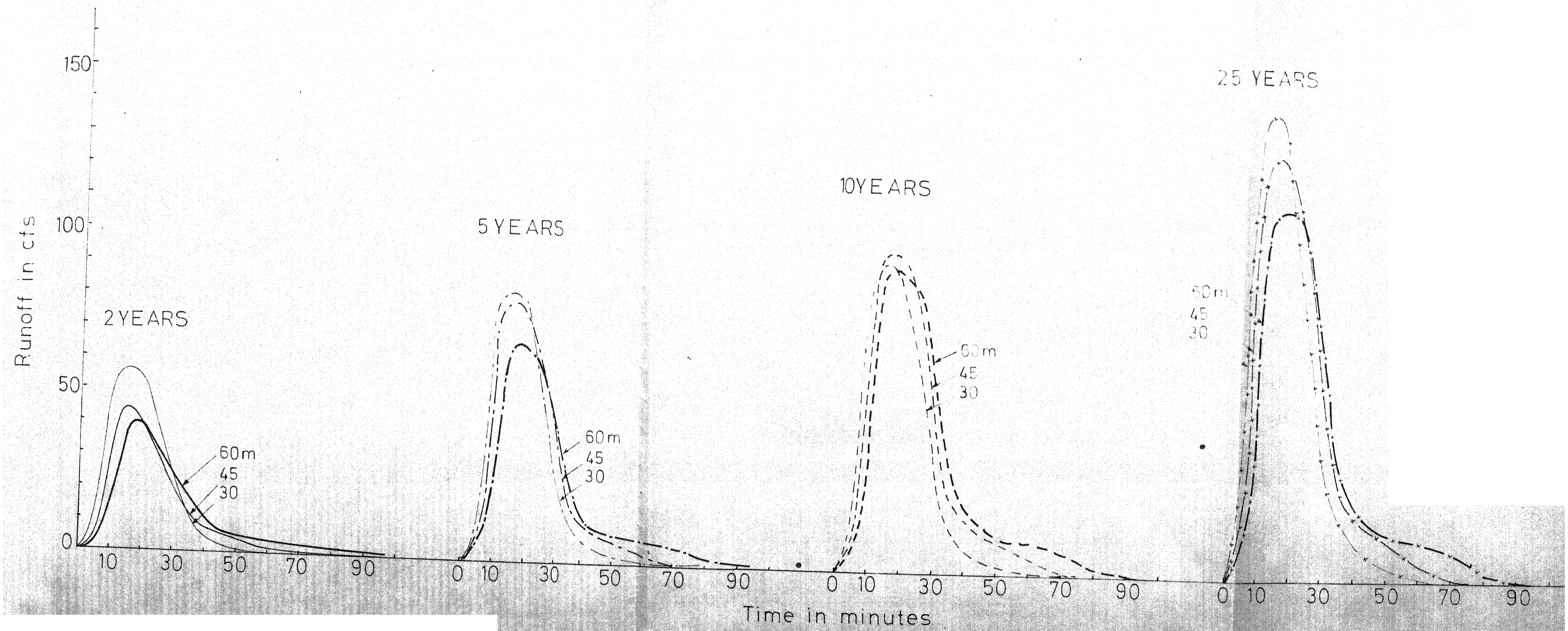
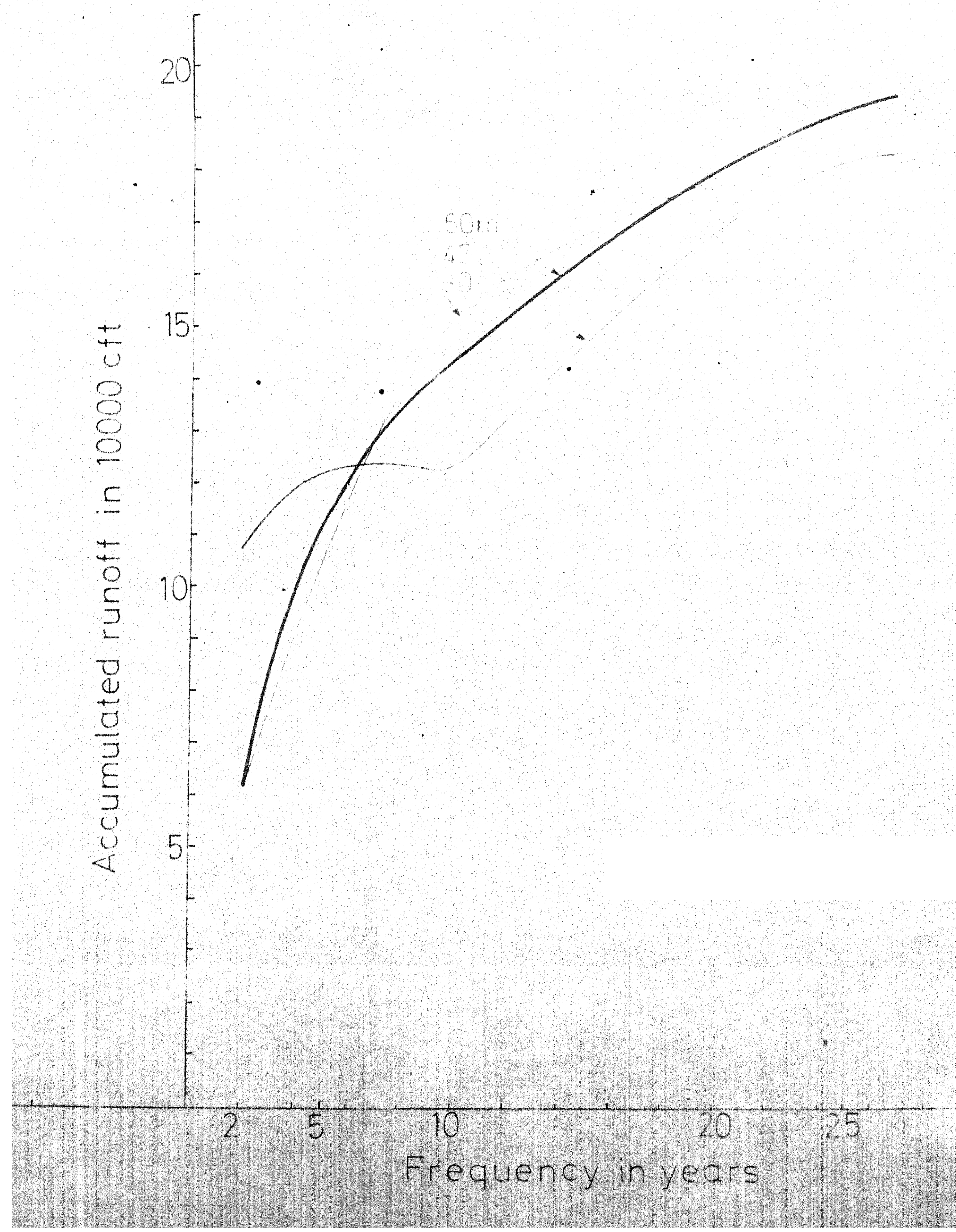


FIG. 3.13 ACCUMULATED RUNOFF AND OUTFALL HYDROGRAPHS


Accumulated runoff in 10000 cft
20
15
10
5
2
5
10
20
25
Frequency in years

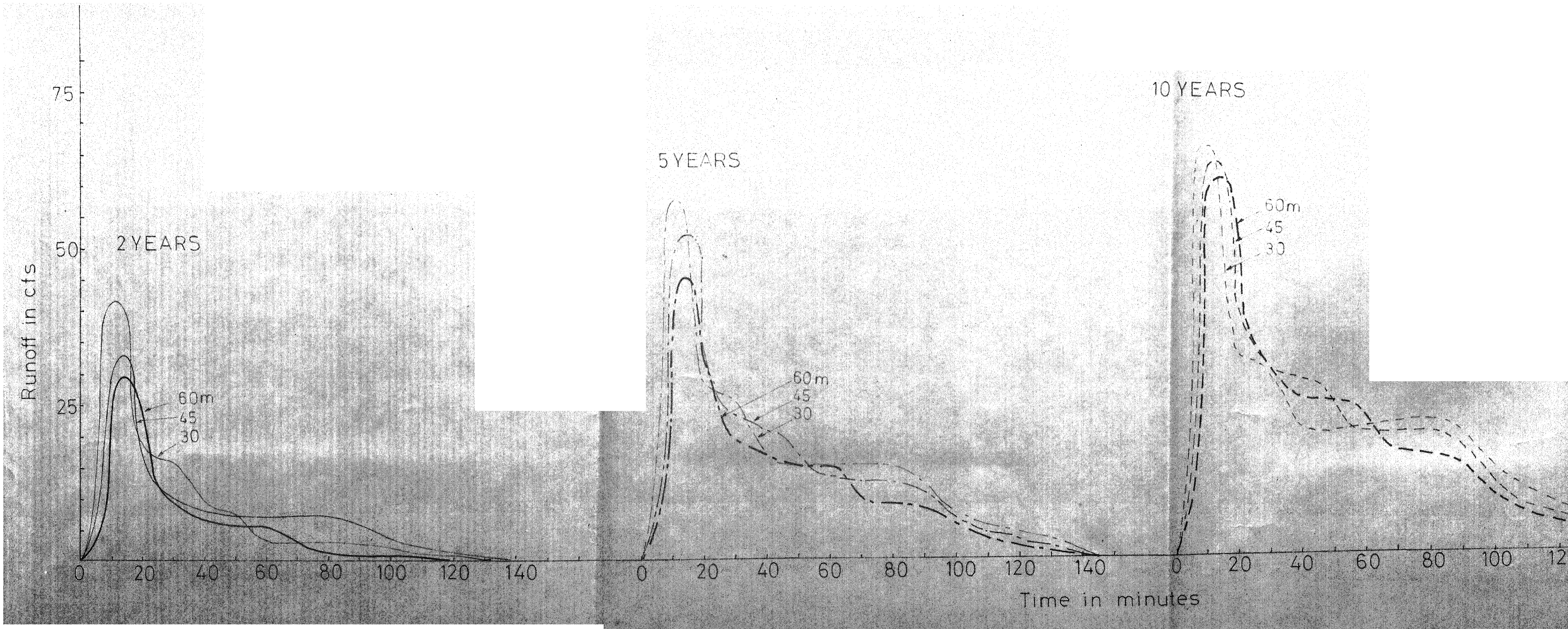
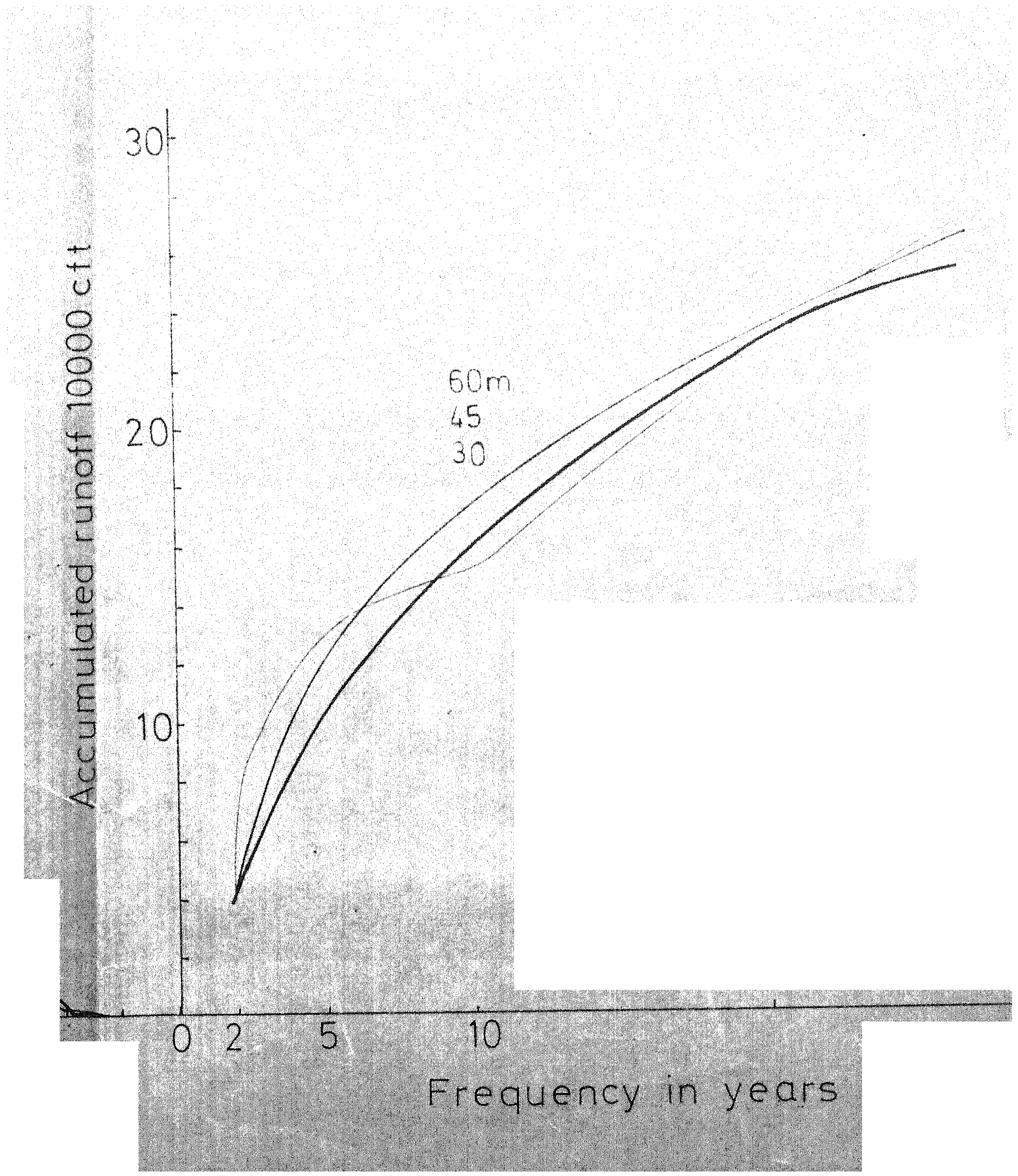


FIG 3.14 ACCUMULATED RUNOFF AND OUTFALL HYDROGRAPH FOR SUBSYSTEM


Accumulated runoff 10000 cft
30
20
10
60m
45
30
0
2
5
10
Frequency in years

infiltration characteristics and rather dry antecedent moisture condition with ILLUDAS number 2 results in negligible contribution from the grassed areas towards the peak flow. It may be necessary to have more detailed survey data for grass inlet time as well as the contributing areas and soil antecedent moisture conditions in order that the limitations due to the above mentioned assumptions can be well understood.

The design diameters shown in Fig.3.7 to 3.10 indicate that in 30 minutes duration storm dominates over other durations, and also that higher durations, and also that higher frequencies require larger diameter and result in higher peak. Economics should decide the choice of an appropriate frequency, and for residential areas frequency of larger than five years is generally not needed. The diameter for five years frequency generally corresponds to a diameter about 3 inches larger for upper reaches and 6 inches to 9 inches larger for the lower reaches than that for a 2 years frequency.

For Indian Institute of Technology, Kanpur campus area a 2 years frequency seems justified and hence the 2 years 30 minutes design is recommended for adoption.

4. A PRILIMINARY STUDY OF PUNJAB URBAN DRAINAGE SYSTEMS

4.1 Introduction

Urban drainage systems are being planned for several major cities of Punjab as part of an IDA Project. It is proposed to study the factors involved in the design of such drainage system for one zone each of Amritsar, Jullendhar, and Ludhiana. Because data could not be obtained in the earlier stages of the study and a lot of field data were not available for the study, the study will deal with only preliminary analysis of the broad aspects of design of the systems to identify pertinent factors for a more rigorous analysis and design.

4.2 Details of Data and System

The details of the drainage system considered in this study are shown in Figs. 4.1, 4.2 and 4.3 respectively for the cities of Amritsar, Jullendhar, and Ludhiana. The same order is always maintained in the presentation of the results of the study. The designation of major nodes and branches are given in the figures and the design details including the length, diameter and slopes of the branches are shown in Tables 4.1, 4.2, and 4.3 respectively for the three cities.

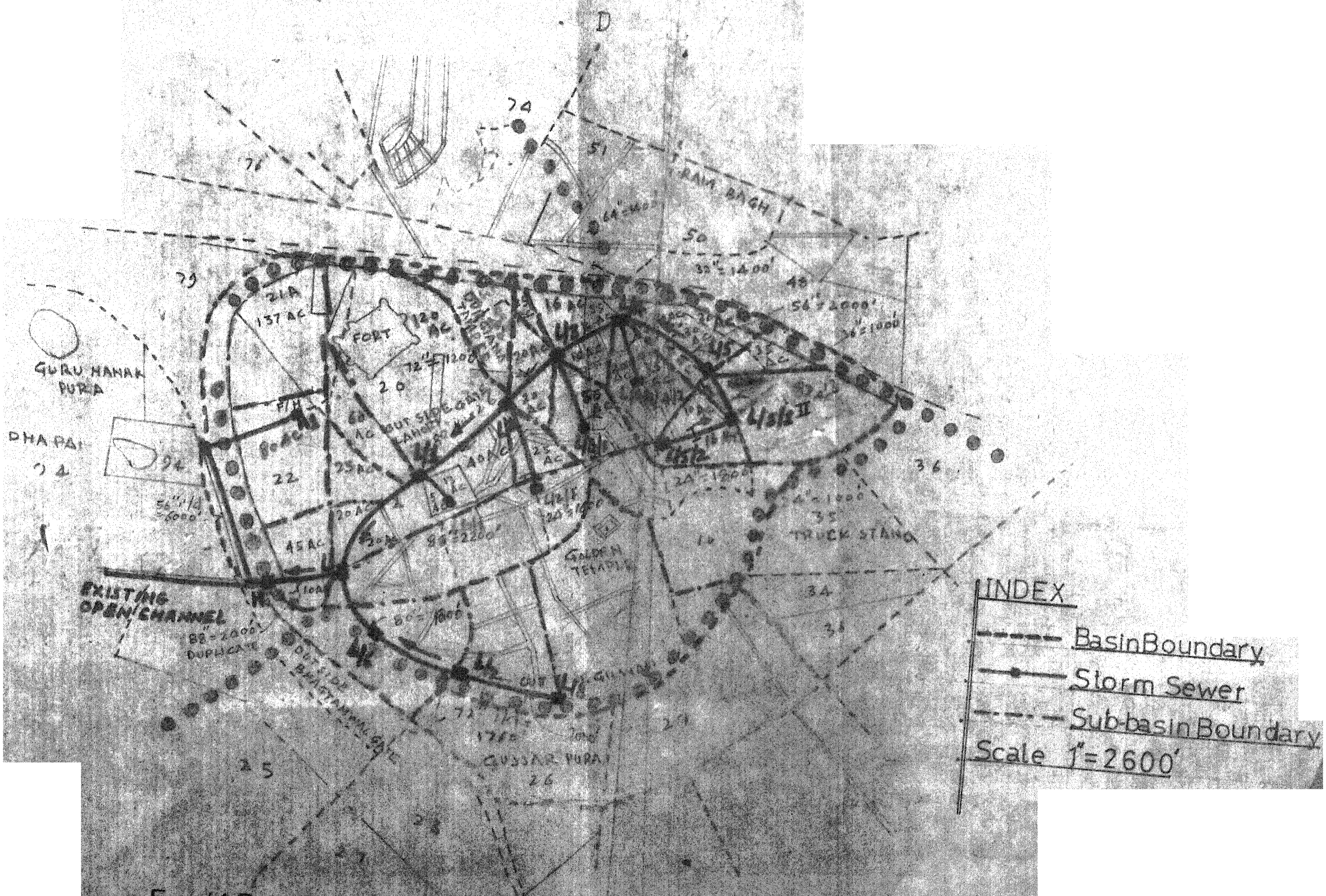
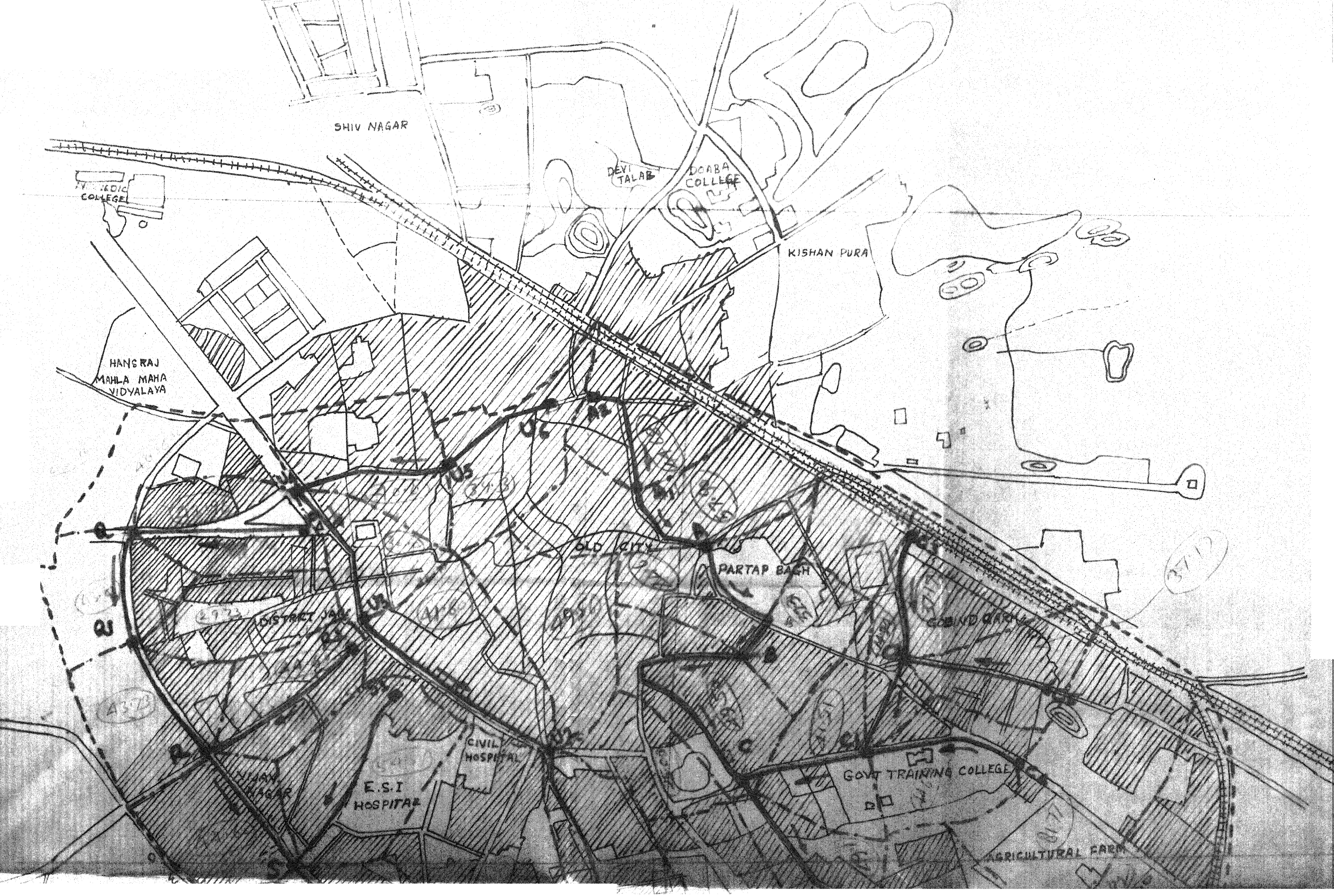


Fig. 4.1 Details of Drainage System of Amritsar (Walled City)


SHIV NAGAR
DEVI TALAB
DOABA COLLEGE
KISHAN PURA
HANSRAJ MAHLA MAHA VIDYALAYA
OLD CITY
PARTAP BAGH
DISTRICT JAIL
GOBIND GARH
CIVIL HOSPITAL
E.S.I HOSPITAL
VIJAY NAGAR
GOVT TRAINING COLLEGE
AGRICULTURAL FARM

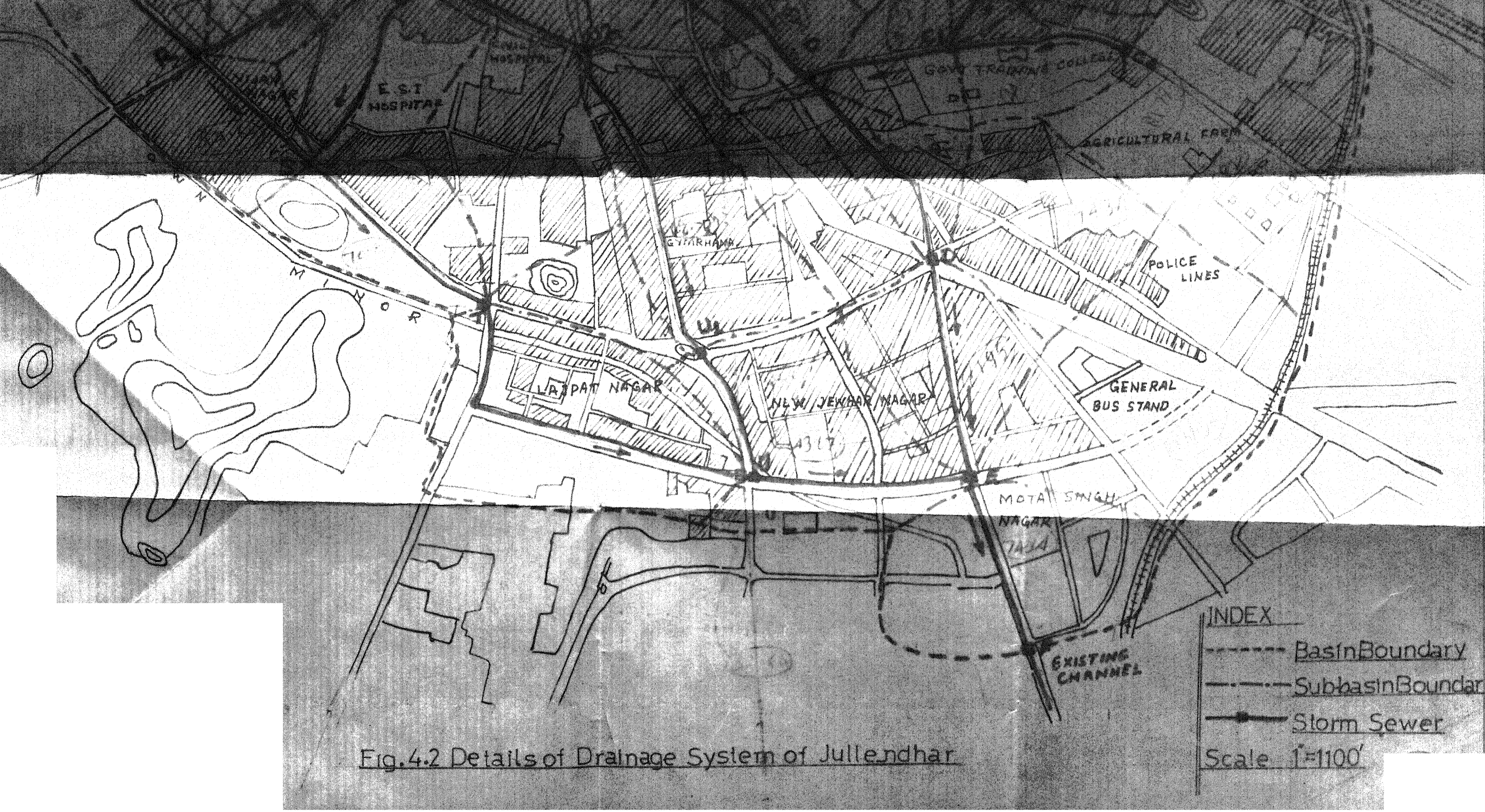


Fig. 4.2 Details of Drainage System of Jullendhar

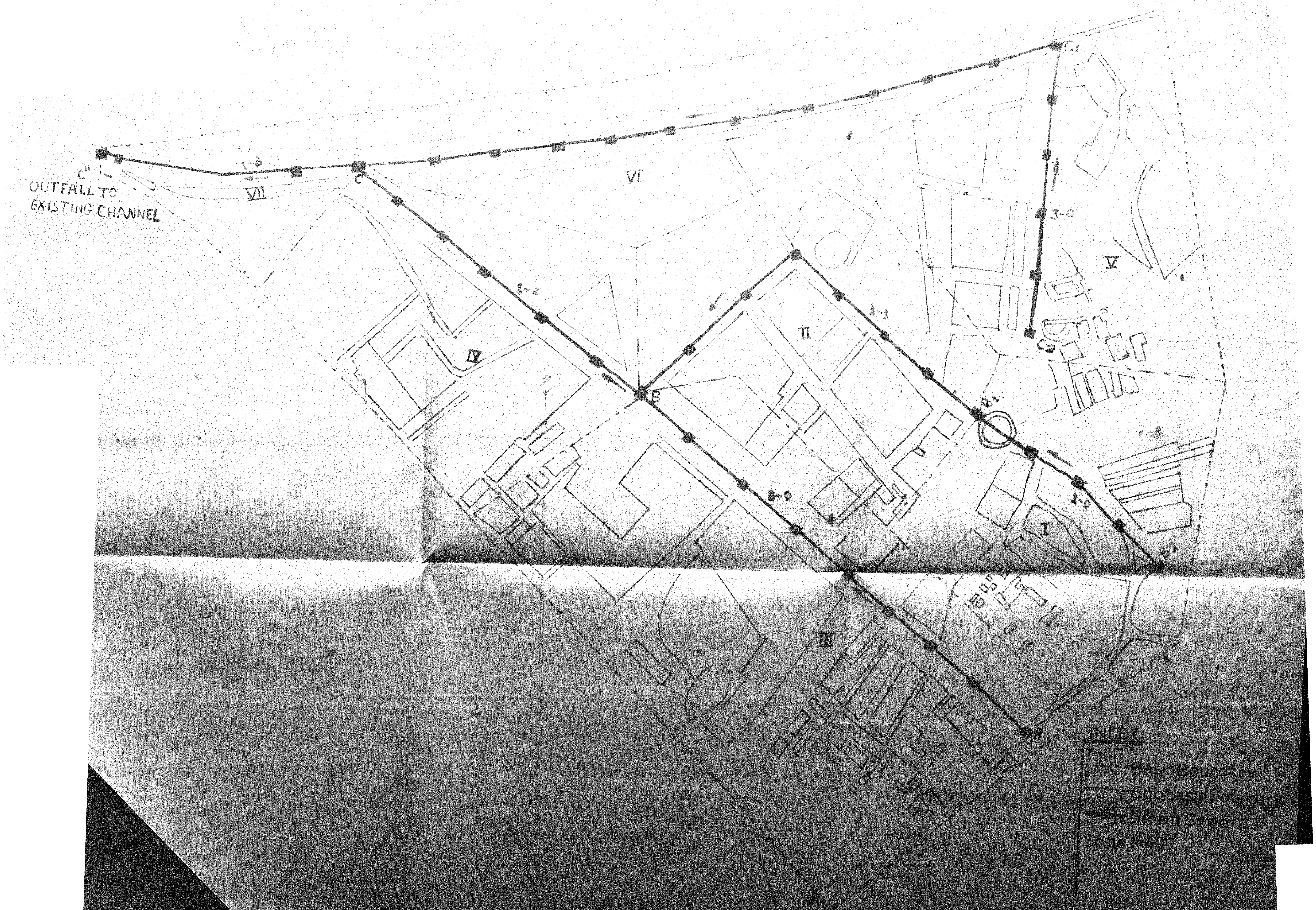


Fig. ... Details of Drainage System of Ludhiana (Pratap Chowk to Dholewal Chowk)

TABLE 4.1 : DATA FOR AMRITSAR CITY SUBSYSTEM

Reach					Sub-basins			
Name of Sewer	Branch and reach number	Length in(ft)	Slope (%)	Dia. in inches	Area (acres)	Directly connected paved area (acres)	Supplemental paved area (acres)	Contributing grassed area (acres)
1	2	3	4	5	6	7	8	9
L/5/2-L/5/1	1-0	1000	.066	24	28.60	13.72	5.72	9.15
L/5/1-L/5	1-1	1000	.048	36	95.70	47.85	19.14	28.71
L/5-L/4	1-2	2000	.028	56	173.80	86.90	34.70	52.10
L/4/1-L/4	2-0	1400	.048	32	60.50	30.20	12.10	18.10
CONFLUENCE								
L/4-L/3	1-3	1400	.028	64	16.10	8.00	3.20	4.80
L/3/1-L/3	3-0	1300	.083	24	55.00	27.50	11.00	16.50
CONFLUENCE								
L/3-L/2	1-4	1200	.028	72	174.50	87.20	34.90	52.30
L/2/1-L/2	4-0.	1600	.083	24	55.00	27.50	11.00	16.50
CONFLUENCE								
L/2-L/1	1-5	2600	.035	80	214.20	107.10	42.80	64.20
L/1/1-L/1	5-0	800	.057	28	22.00	11.00	4.40	6.60
CONFLUENCE								
L/1-D	1-6	2200	.028	88	159.50	79.75	31.90	47.85
L/8-L/7	6-0	2000	.028	72	449.00	224.50	89.80	134.70

Contd.....

Table 4.1 contd....

1	2	3	4	5	6	7	8	9
L/7-L/6	6-1	1760	.028	72	241.9	120.8	48.3	72.4
L/6-L	6-2	1800	.028	80	213.4	106.7	42.6	64.0
CONFLUENCE								
L-H	1-7	2000	.028	88	75.0	37.5	15.0	22.5
H/2-H/1	7-0	2000	.028	56	142.7	71.3	28.5	42.8
H/1-H	7-1	4000	.028	56	80.0	40.0	16.0	24.0
CONFLUENCE								
H-K	1-8	4600	.028	120	-	-	-	-
			Total		2257.22			

TABLE 4.2 : DATA FOR JULLENDHAR CITY SUBSYSTEM

	2	3	4	5	6	7	8	9
A2-A1	1-0	1500	.033	36	44.68	40.2	-	4.46
A1-A	1-1	1500	.033	48	57.99	52.2	-	5.79
A-B	1-2	1200	.028	60	44.60	40.20	-	4.60
B-C	1-3	2400	.028	66	49.56	44.66	-	4.90
C3-C2	2-0	1400	.033	46	37.17	33.47	-	3.70
C5-C2	3-0	1600	.033	38	37.17	33.47	-	3.70
CONFLUENCE								
C2-C1	2-1	1000	.033	48	14.94	13.54	-	1.40

Table 4.2 contd...

1	2	3	4	5	6	7	8	9
C4-C1	4-0	1800	.033	36	44.60	40.20	-	4.4
CONFLUENCE								
C1-C	2-2	1400	.028	60	41.51	37.41	-	4.1
CONFLUENCE								
C-D	1-4	2600	.028	85	49.56	44.66	-	4.9
D-E	1-5	2200	.028	101	61.95	55.85	-	6.1
U6-U5	5-0	1400	.033	36	39.60	35.40	-	3.9
U5-U4	5-1	1300	.033	48	40.00	36.00	-	4.0
U4-U3	5-2	1800	.040	48	30.00	27.00	-	3.0
U3-U2	5-3	2200	.040	60	41.60	37.50	-	4.1
U2-U1	5-4	3200	.040	66	86.73	78.13	-	8.6
U1-U	5-5	1500	.100	66	32.65	29.45	-	3.2
P-Q	6-0	2000	.033	36	43.96	39.57	-	4.3
Q-Q1	6-1	1350	.062	48	43.00	38.70	-	4.3
Q1-R	6-2	1350	.041	60	43.73	39.36	-	4.37
R1-R	7-0	2200	.033	36	44.60	40.14	-	4.4
CONFLUENCE								
R-S	6-3	1500	.040	66	44.60	40.14	-	4.46
S1-S	8-0	2500	.045	36	54.51	49.11	-	5.4
CONFLUENCE								
S-T	6-4	2300	.050	72	70.00	63.00	-	7.0
T-U	6-5	4000	.032	94	89.67	80.77	-	8.9
CONFLUENCE								
U-E	5-6	2200	.045	102	49.57	44.67	-	4.9
CONFLUENCE								
E-F	1-6	2200	.033	140	74.34	66.91	-	7.43
			Total		1312.05			

TABLE 4.3 : DATA FOR LUDHIANA CITY SUBSYSTEM

Reach					Subbasins			
Name of Sewer	Branch and reach number	Length in(ft)	Slope (%)	Dia. in inches	Area (acres)	Directly connected paved area (acres)	Supplemental paved area (acres)	Contributing grassed area (acres
B2-B1	1-0	1300	.083	30	70.0	28.0	21.0	21.0
B1-B	1-1	3000	.100	36	80.6	32.0	24.0	24.0
A-B	2-0	3200	.100	36	160.0	64.0	48.0	48.0
CONFLUENCE								
B-C	1-2	2200	.058	54	72.69	29.07	21.8	21.8
C2-C1	3-0	2000	.083	30	100.5	40.2	30.15	30.15
C1-C	3-1	4500	.071	39	83.6	33.44	25.08	25.08
CONFLUENCE								
C-C"	1-3	1000	.100	57	28.5	11.4	8.55	8.55
			Total		595.29			

Due to limitations of time, connected paved areas, unconnected paved areas and contributing grassed areas could not be obtained. It is assumed that 70 to 90 percent of the area is paved and the remainder is the grassed area contributing to the system. In reality except in the heavily built up area of the city the paved area will not be more than one third to half of total area and because of the presence of the parks and grassed land within the city only less than half of the grassed area may contribute directly to immediate runoff from the system. It is not possible to get additional details of data of this aspect and simulate the system more realistically.

The soil is considered to belong to hydrologic group C of the U.S. Soil Conservation Service, with low infiltration rates. The antecedent moisture condition is considered to be defined by ILLUDAS number 2 representing a rather dry condition.

4.3 Design Storm

The details of design storm for Amritsar, Jullendhar, and Ludhiana were obtained from India Meteorological Department (4) for different durations and frequencies. The point rainfall values are shown in Table 4.4. No area correction factor was used and rainfall is assumed to be the

TABLE 4.4 : DEPTH-DURATION-FREQUENCY RELATIONSHIPS FOR AMRITSAR, JULLENDHAR AND LUDHIANA

	Amrittsar and Jullundhar				Ludhiana			
Freque-ncy in Yrs.	Depth in inches				Depth in inches			
	1	2	5	10	1	2	5	10
Duration in(minutes)								
30	1.34	1.37	1.57	1.85	1.29	1.37	1.57	1.96
45	1.50	1.57	1.96	2.20	1.49	1.57	1.96	2.36
60	2.13	2.16	2.28	2.55	1.65	1.77	2.24	2.75

same as point rainfall.

4.4 Analysis of Existing Systems

4.4.1 Analysis and results

Since the details of the actual design of master plan are available for the study, it is proposed to analyse the system for storms of different frequencies and durations. The results of analysis are presented:

i) With a peak discharge and detention storages for different storms shown in Table 4.5, 4.6 and 4.7 respectively for the three cities; and

ii) The characteristics of flood hydrograph at outfall being shown in Table 4.8.

4.4.2 Discussion of Results

The results indicate a detention storage of the order of 150 to 516 thousands cft corresponding to about 3 to 10 percent of the actual storm runoff. The actual discharge as per the analysis are much larger than provided for in the master plan. The persistent flow of outfall hydrograph also indicate inadequate capacity.

The high flood runoff indicated may be very biased because of the assumption of low infiltration rates due

TABLE 4.5 : PEAK DISCHARGE , DETENTION STORAGE FOR DIFFERENT STORMS FOR AMRITSAR CITY

	Peak discharge in cfs												Storage in 1000 cft											
Frequency in Yrs. →	1 Year			2 Years			5 Years			10 Years			1 Year			2 Years			5 Years			10 years		
Duration Mts. →	30	45	60	30	45	60	30	45	60	30	45	60	30	45	60	30	45	60	30	45	60	30	45	60
Branch and Reach 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1-0	95	80	109	98	85	104	117	111	111	156	127	126	79	81	134	82	88	137	102	128	149	126	152	176
1-1	333	282	357	343	298	363	406	385	386	503	438	438	293	312	498	303	335	508	369	467	549	451	549	642
1-2	608	517	653	624	545	664	741	703	706	873	800	800	519	548	881	537	591	899	657	829	973	805	977	977
2-0	209	176	223	215	185	227	255	240	241	311	274	274	176	184	297	182	198	303	224	281	329	281	332	386
1-3	67	70	83	68	73	84	79	88	88	82	97	96	14	14	39	15	17	41	24	36	47	36	48	61
3-0	190	160	203	195	169	206	232	219	219	271	249	259	167	176	282	172	190	288	211	265	311	247	312	364
1-4	616	540	677	634	568	687	753	729	730	856	828	826	509	540	887	828	586	906	651	830	981	798	981	1152
4-0	190	160	203	195	169	206	232	219	219	263	249	249	171	183	291	177	197	297	216	273	321	255	320	374
1-5	775	680	848	796	715	861	939	910	913	1028	1030	1029	604	635	1042	626	688	1065	775	982	1155	930	998	1361
5-0	76	64	81	78	66	82	82	87	87	107	99	99	57	55	91	57	60	92	72	89	103	78	108	124
1-6	581	526	651	597	551	660	704	696	699	846	786	785	427	459	775	444	498	792	554	719	861	686	856	1015

Contd......

Table 4.5 contd...

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	2.
6-0	1554	13[illegible]6	1659	1599	1380	1686	1897	1788	1794	2148	2039	2037	1327	1390	2236	1374	1501	2284	1685	2116	2475	1985	2.
6-1	855	742	932	879	782	946	1040	1001	1004	1183	1136	1136	748	814	1312	774	875	1338	947	1214	1442	1143	1.
6-2	760	664	831	782	699	844	924	893	896	1053	1012	1012	609	646	1056	631	698	1079	779	991	1171	961	1
1-7	332	347	406	338	359	410	382	428	429	503	469	469	271	2968	4793.	2811	3192	488	3451	4433	5268	4084	5
7-0	494	415	527	568	438	536	603	568	570	693	648	647	393	401	657	408	436	672	507	631	733	599	[illegible]
7-1	284	250	313	292	263	317	345	336	337	393	380	380	334	255	419	243	275	428	300	388	463	355	[illegible]
1-8	157	157	157	157	157	157	157	157	157	157	157	157	-	-	-	-	-	-	-	-	-	-	-

TABLE 4.6 : PEAK DISCHARGE, DETENTION STORAGE FOR DIFFERENT STORMS FOR JULLENDHAR

	Peak discharge in cfs												Storage in 1000 cft											
Frequency in Yrs.	1 Year			2 years			5 years			10 years			1 year			2 years			5 years			10 years		
Duration Mts.	30	45	60	30	45	60	30	45	60	30	45	60	30	45	60	30	45	60	30	45	60	30	45	60
Branch and Reach 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1-0	229	179	203	247	192	193	263	242	244	376	298	304	150	179	164	162	180	198	221	241	268	255	304	352
1-1	301	239	201	323	198	256	268	321	256	492	389	401	190	229	180	206	165	254	263	308	251	326	390	454
1-2	237	195	246	255	265	208	243	258	332	385	309	320	122	142	131	135	211	160	196	207	323	228	271	314
1-3	273	231	231	292	246	246	297	301	303	436	358	370	147	179	167	160	179	200	236	247	277	263	317	371
2-0	191	149	148	205	160	160	209	201	203	313	248	253	121	142	132	131	144	157	183	194	215	208	247	285
3-0	191	149	148	205	160	160	209	201	203	313	248	253	117	135	126	127	138	150	177	188	208	204	241	278
2-1	83	74	73	89	78	78	99	95	95	133	112	116	40	55	45	44	54	61	63	72	84	75	93	113
4-0	229	179	179	247	192	192	253	242	244	376	247	304	140	179	163	162	180	198	229	240	268	255	304	352
2-2	228	192	192	244	205	205	248	251	253	365	299	309	128	162	141	140	159	180	201	216	245	226	274	323
1-4	282	254	254	301	269	269	321	324	326	445	381	393	95	130	111	109	124	148	182	191	218	212	261	312
1-5	344	297	296	368	323	318	389	393	395	549	464	479	53	63	59	65	74	80	110	129	149	183	206	235

Contd.........

Table 4.6 contd...

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5-0	202	157	157	217	169	170	221	213	215	332	262	268	129	152	141	140	154	168	193	207	230	221	263	304
5-1	208	167	167	224	179	179	234	224	225	341	270	279	119	140	133	130	143	156	179	197	218	213	253	294
5-2	163	131	137	175	147	147	202	180	181	262	215	222	97	126	112	106	122	138	145	162	185	168	205	242
5-3	222	183	182	238	195	196	280	243	244	359	290	300	97	103	99	108	114	119	148	169	183	193	227	261
5-4	459	376	376	494	402	403	578	493	502	745	599	620	273	340	309	297	336	376	408	454	513	477	576	677
5-5	180	158	157	193	168	168	231	204	205	288	242	249	18	21	19	23	25	28	43	50	58	71	82	98
6-0	226	176	175	243	189	190	281	238	240	371	293	299	147	185	163	159	176	194	203	236	263	250	298	346
6-1	223	177	176	240	190	190	281	238	240	365	289	298	110	117	113	122	128	123	168	185	201	209	245	181
6-2	242	204	203	259	217	218	302	266	268	386	316	327	120	140	134	132	145	158	186	204	226	223	265	308
7-0	229	179	178	247	192	193	286	242	244	376	297	304	150	179	167	162	179	197	204	240	267	254	303	351
6-3	254	224	223	272	237	237	331	287	289	401	338	349	133	177	154	146	170	195	207	231	265	238	294	350
8-0	280	219	218	301	235	235	357	296	298	460	364	372	185	221	201	200	222	214	267	296	230	313	373	323
6-4	392	339	338	419	360	361	501	438	441	623	519	537	205	257	240	224	254	286	330	350	396	369	449	529
6-5	491	419	418	527	445	446	621	546	549	787	649	671	178	187	181	202	204	214	303	324	346	382	448	513
5-6	335	339	338	359	360	358	417	419	418	510	478	489	91	166	136	105	155	200	219	237	305	228	327	433
1-6	509	515	510	534	558	541	642	662	647	774	758	767	23	33	27	38	36	49	102	123	135	162	220	272

TABLE 4.7 PEAK DISCHARGE, DETENTION STORAGE FOR DIFFERENT STORM FOR LUDHIANA

	Peak discharge in cfs												Storage in 1000 cft.											
Frequency in Yrs. →	1 year			2 years			5 years			10 years			1 year			2 years			5 years			10 years		
Duration Mts. →	30	45	60	30	45	60	30	45	60	30	45	60	30	45	60	30	45	60	30	45	60	30	45	60
Branch and Reach 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1-0	203	188	175	219	200	191	260	260	252	340	321	319	193	212	227	212	232	257	260	328	373	357	427	501
1-1	236	209	255	237	227	302	306	297	393	376	374	223	249	270	245	272	304	302	382	438	413	497	454	584
2-0	464	429	401	501	457	437	595	594	577	777	735	730	454	504	544	598	548	611	610	769	879	833	997	1171
1-2	218	213	200	235	226	217	278	288	281	361	352	350	179	203	223	199	223	255	251	324	377	352	429	510
3-0	291	269	251	314	237	274	373	373	363	488	461	459	288	320	347	316	349	389	387	487	558	527	632	742
3-1	245	230	215	265	245	234	314	317	308	409	390	388	230	256	278	253	280	313	372	395	453	428	575	606
1-3	104	110	109	109	115	115	123	139	139	154	164	165	33	41	49	40	49	60	57	84	105	92	121	153

TABLE 4.8: CHARACTERISTICS OF OUTFALL FLOOD HYDROGRAPH

For Amritsar

Frequency in years	Time to Peak in minutes			Peak discharge in cfs			Accumulated runoff in 100000 cft		
	30 Min.	45 Min.	60 Min.	30 Min.	45 Min.	60 Min.	30 Min.	45 Min.	60 Min.
1	2	3	4	5	6	7	8	9	10
1	310	310	310	157	157	157	74.6	81.0	127.6
2	280	280	280	157	157	157	77.1	86.7	130.1
5	280	280	280	157	157	157	93.3	184.4	139.8
10	280	280	280	157	157	157	113.4	137.9	161.7
		For Jullenchar							
1	35	60	60	436	443	448	51.6	57.3	66.6
2	40	50	65	440	445	449	55.3	63.6	72.0
5	70	80	100	448	451	452	75.6	81.5	92.6
10	75	110	130	451	452	453	82.5	100.0	117.6
		For Ludhinana							
1	85	85	85	72	72	72	18.85	21.39	23.6
2	85	85	85	72	72	72	20.56	23.11	26.18
5	75	85	85	72	72	72	24.85	31.46	36.25
10	80	80	85	72	72	72	33.20	40.04	47.18

to soil type C assumed in this study and the assumptions of a larger percentage of paved areas and contributing grassed areas. In reality the actual flood hydrograph may be very much smaller than those given in this study because of the above limitations.

4.5 Design of New Systems

4.5.1 Analysis of results

Assuming that the assumptions of the earlier sections are valid, designs of the urban drainage system for different frequencies and durations were made using ILLUDAS. The results of the study are presented with:

i) Figs. 4.4, 4.5 and 4.6 showing the designed system along the main line for the three cities;

ii) Figs. 4.7, 4.8 and 4.9 showing the corresponding maximum discharges for the three cities; and

iii) Figs. 4.10, 4.11 and 4.12 showing the outfall hydrograph for the three cities.

4.5.2 Discussion of Results

The results presented in previous subsection indicate that the diameters of the drainage system are 2 to 3 times the diameters of master plan if the detention

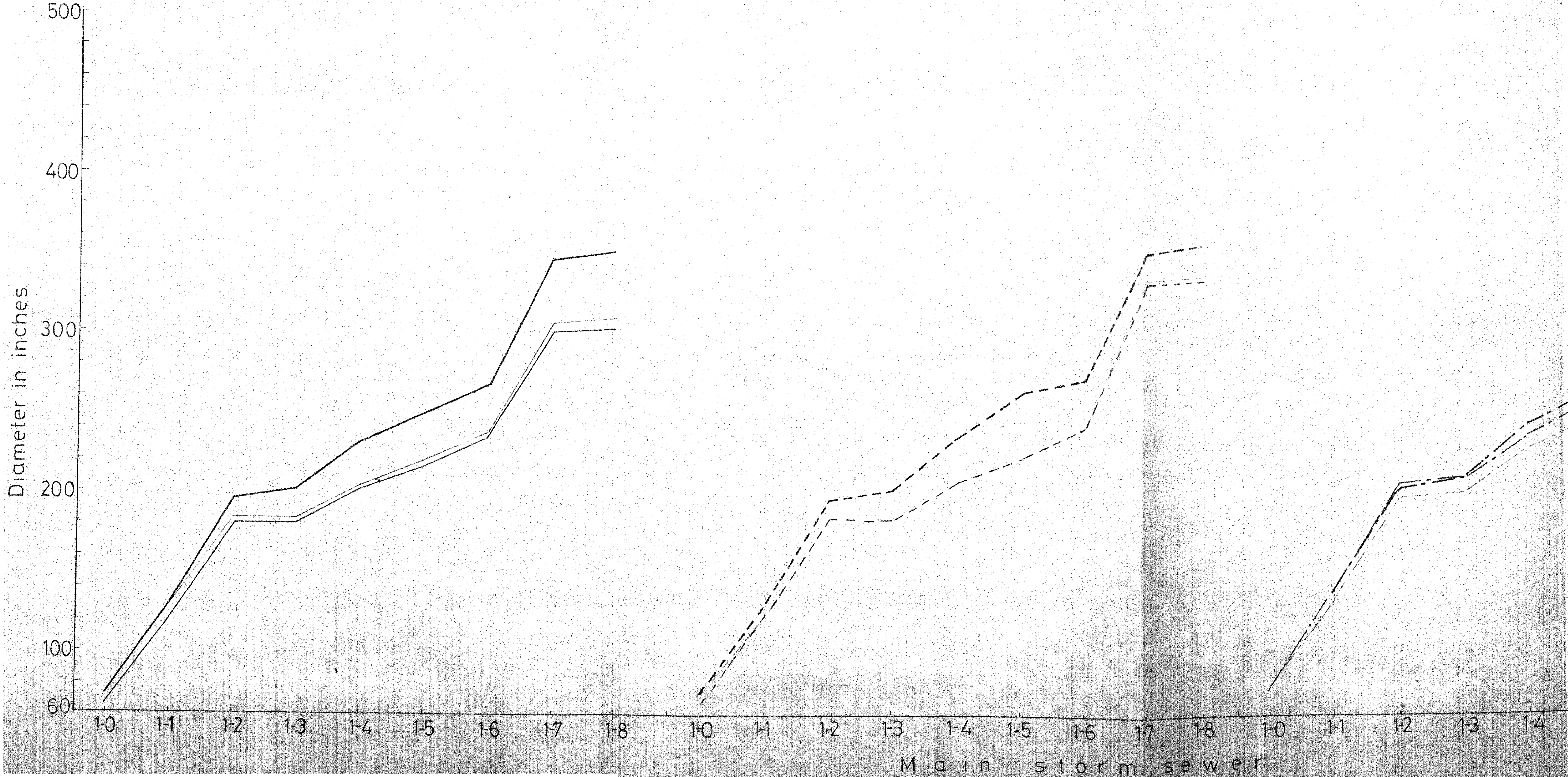
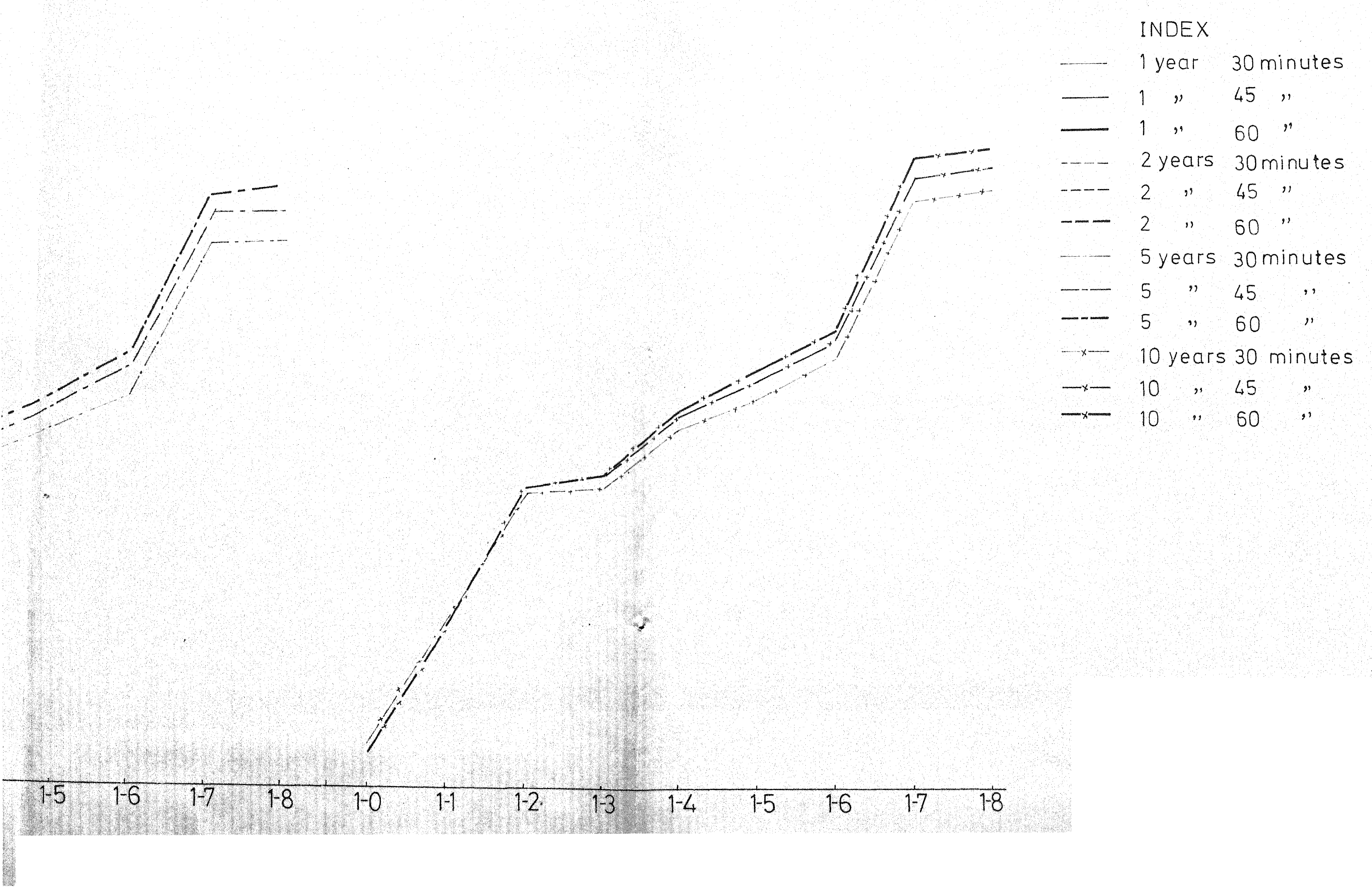


FIG. 4·4 DESIGN DIAMETER ALONG MAIN LINE FOR AMRITSAR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1 year 30 minutes
1 " 45 "
1 " 60 "
2 years 30 minutes
2 " 45 "
2 " 60 "
5 years 30 minutes
5 " 45 "
5 " 60 "
10 years 30 minutes
10 " 45 "
10 " 60 "
1·5
1·6
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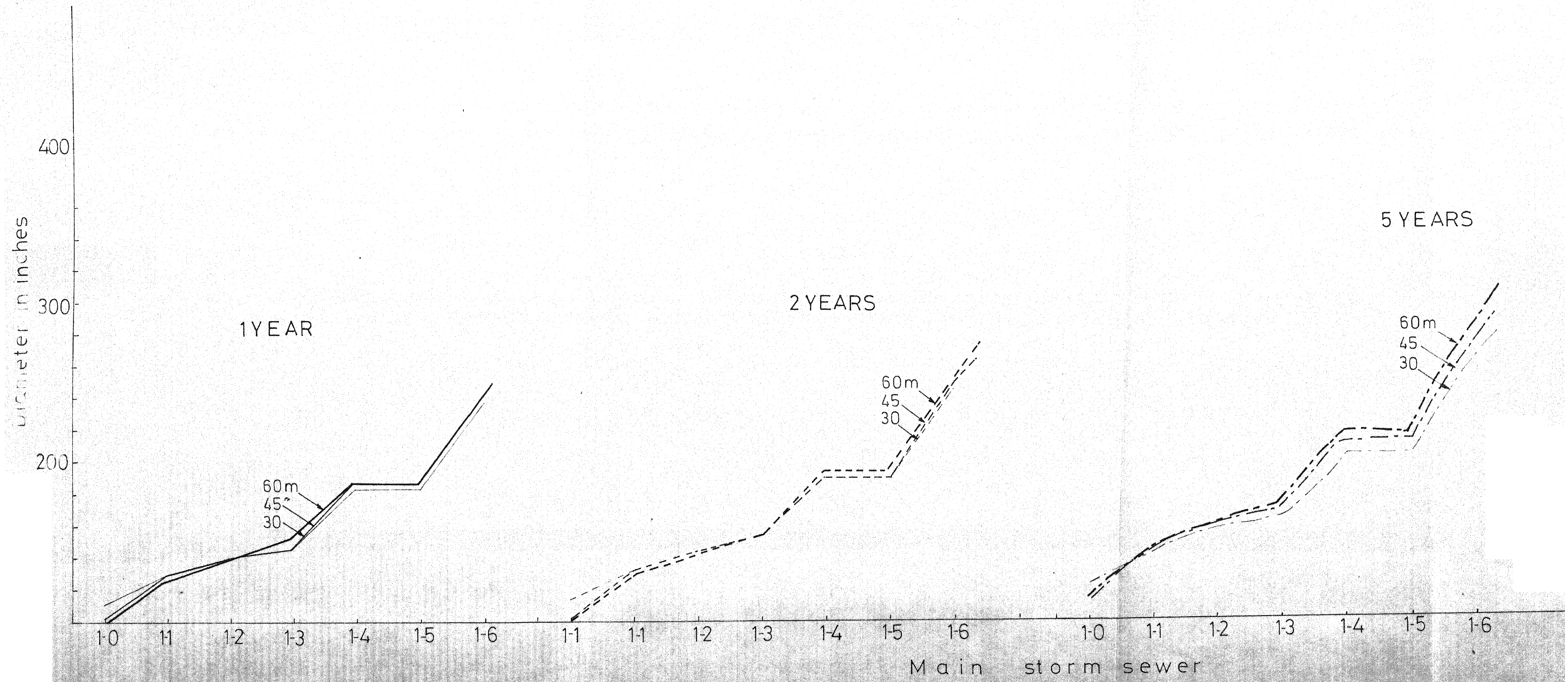
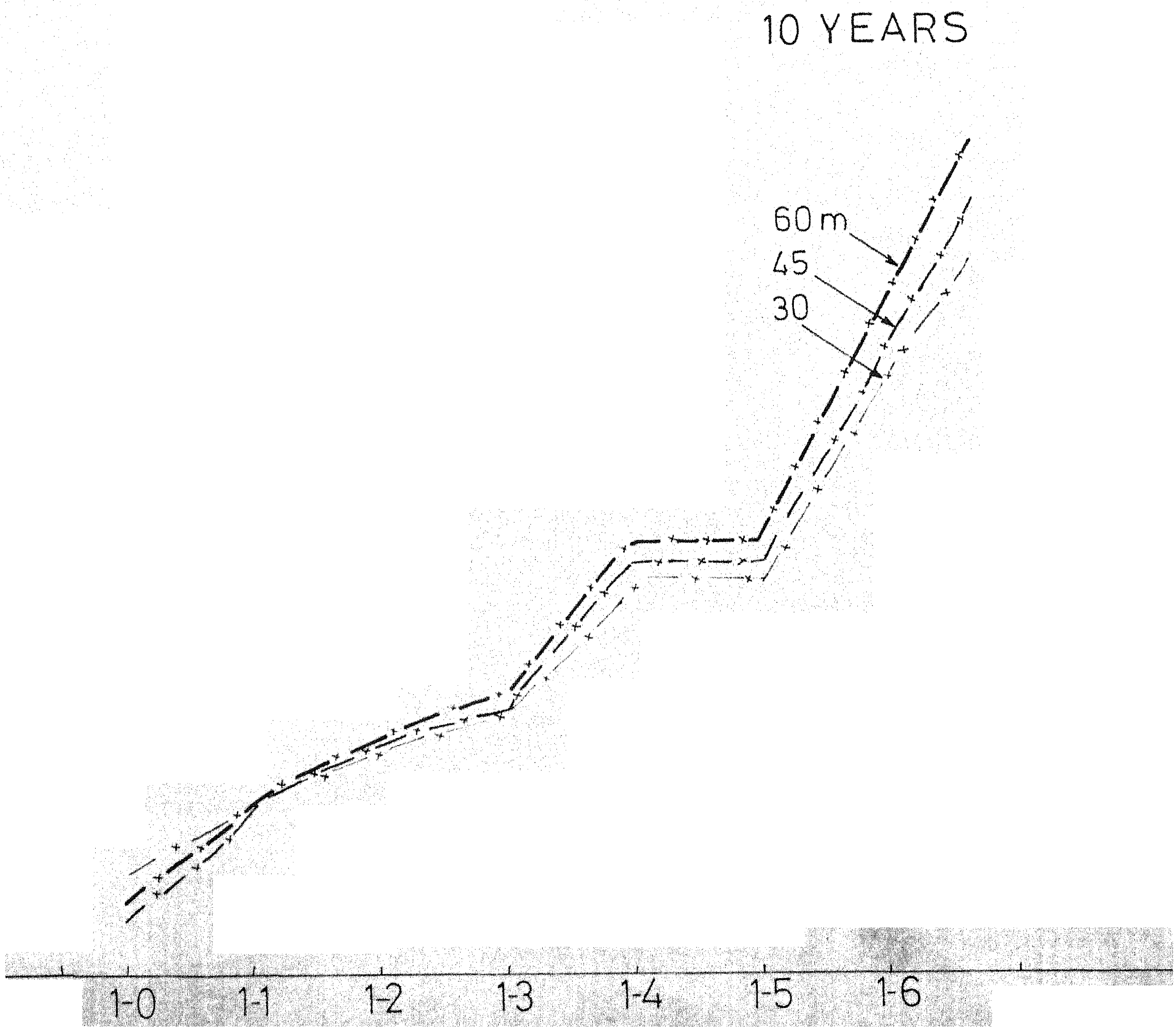


FIG.4.5 DESIGN DIAMETER ALONG MAIN LINE FOR JULLENDHER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30
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1-2
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1-4
1-5
1-6

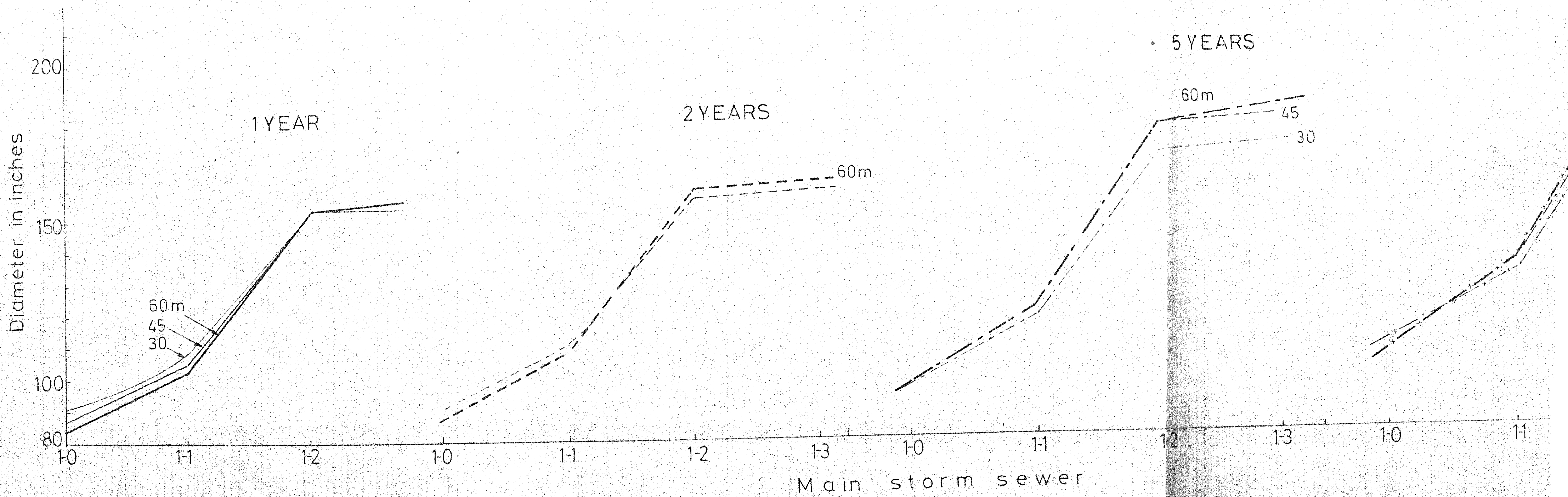
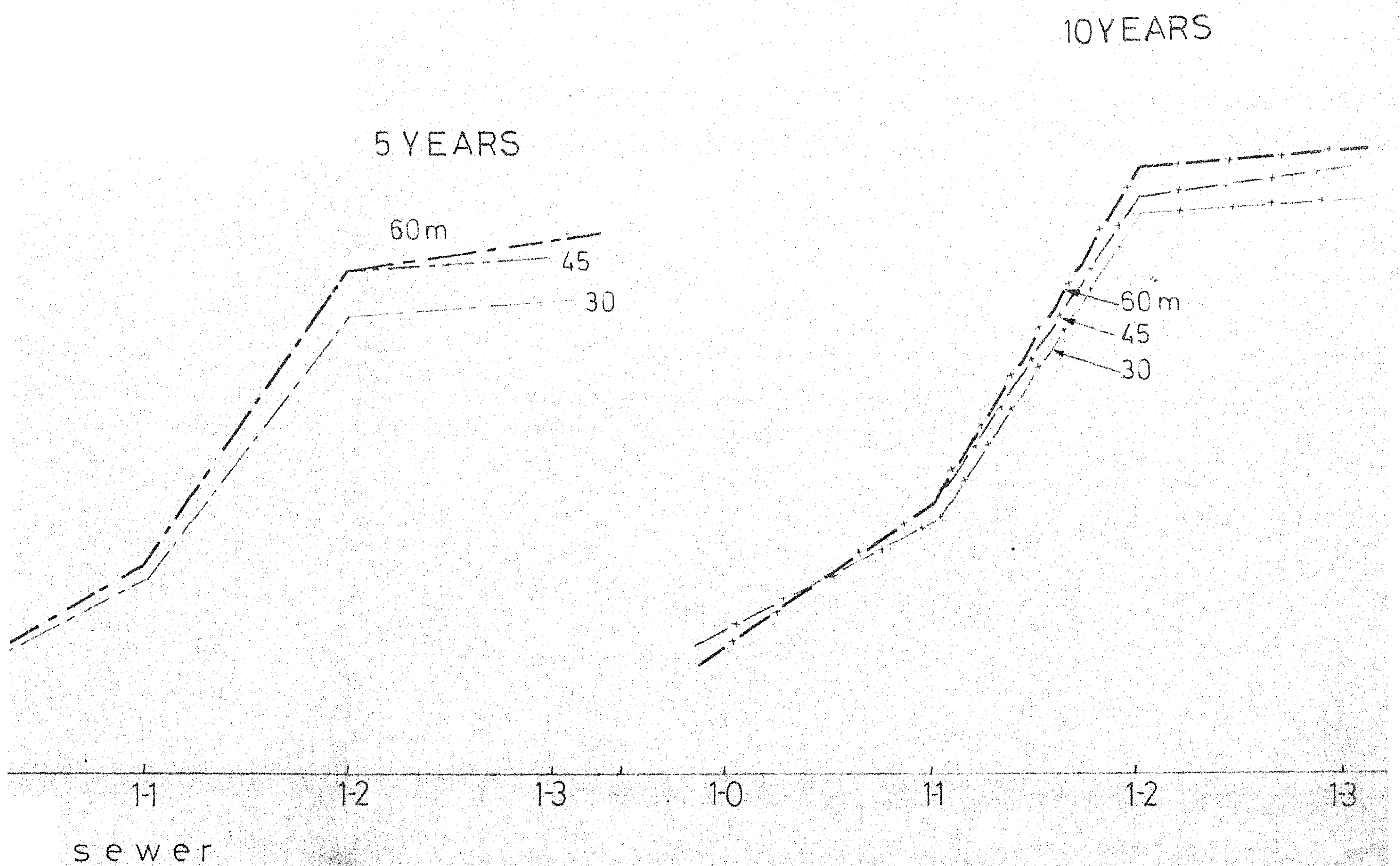


FIG.4.6 DESIGN DIAMETER ALONG MAIN LINE FOR LUDHIANA



ALONG MAIN LINE FOR LUDHIANA

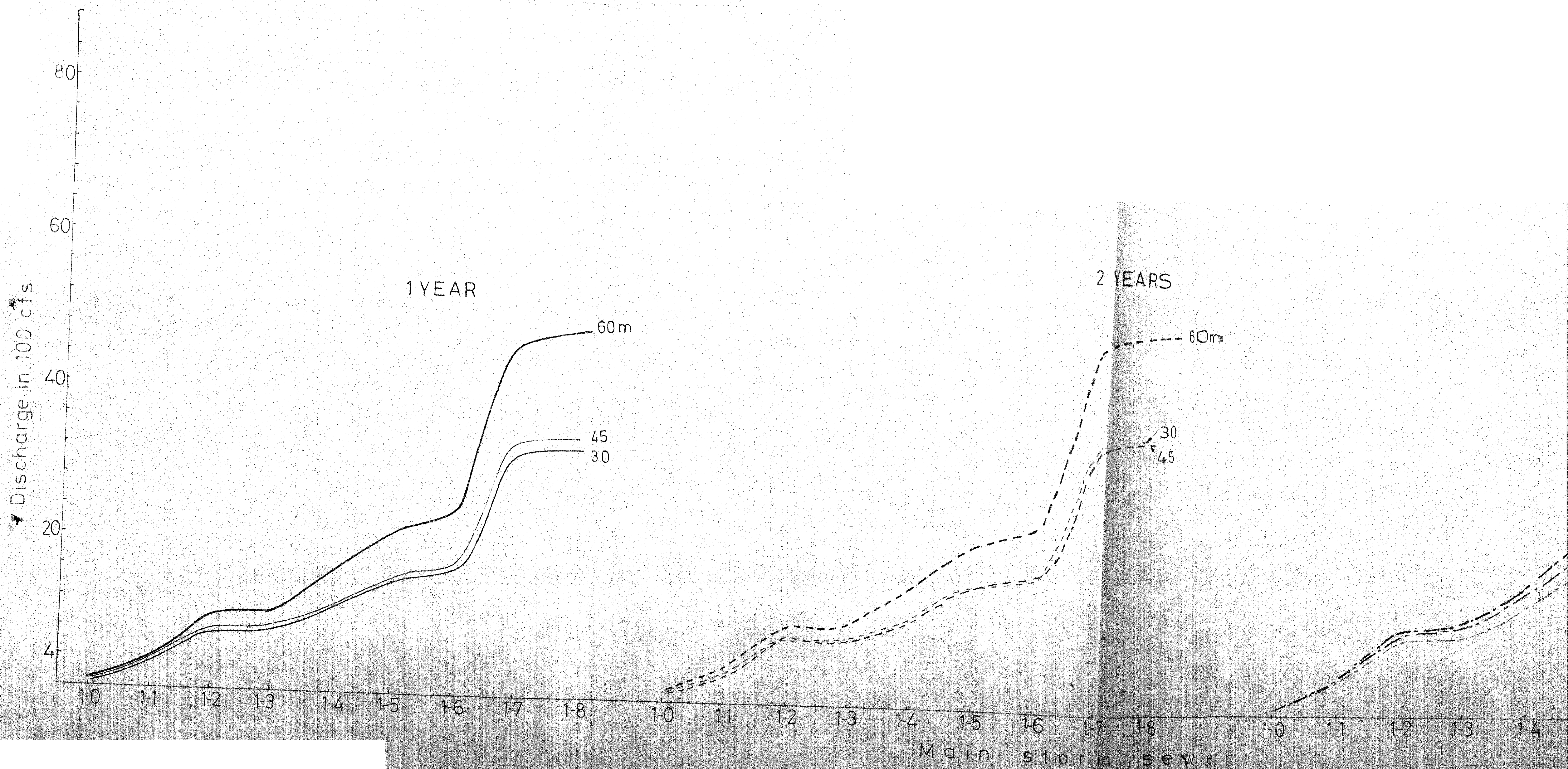


FIG. 4·7 MAXIMUM DISCHARGE ALONG MAIN LINE FOR AMRITSAR

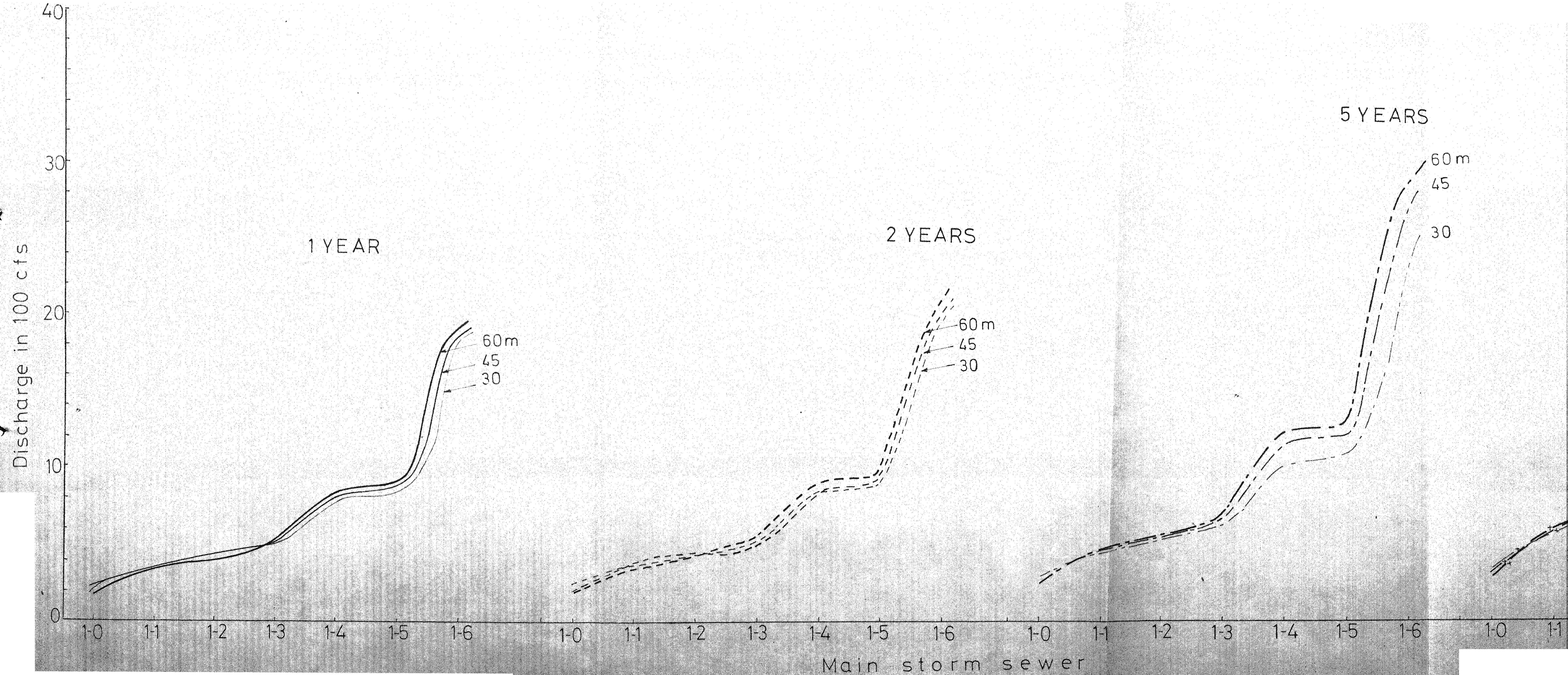
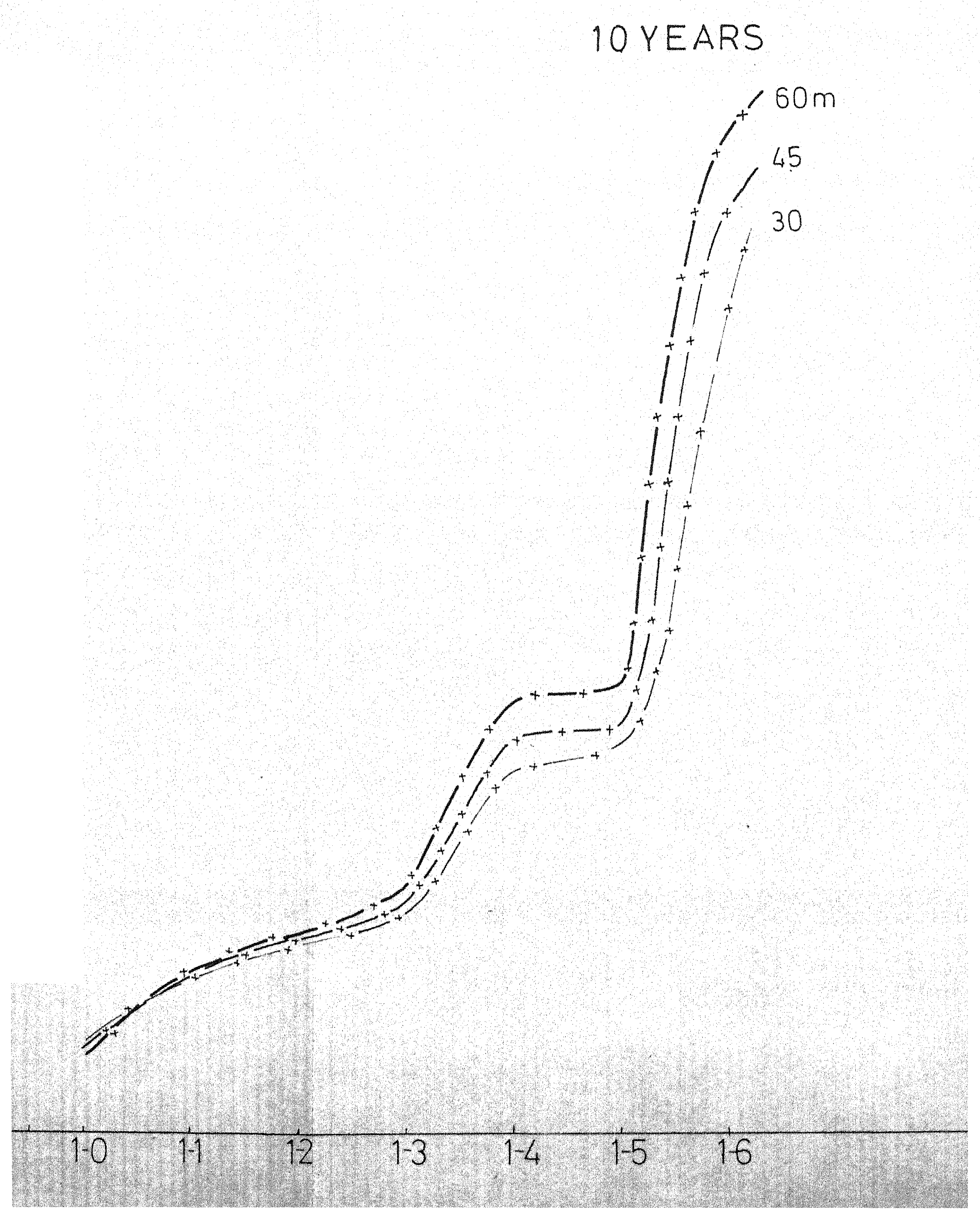


FIG.4.8 MAXIMUM DISCHARGE ALONG MAIN LINE FOR JULLENDHER


10 YEARS
60m
45
30
1-0
1-1
1-2
1-3
1-4
1-5
1-6

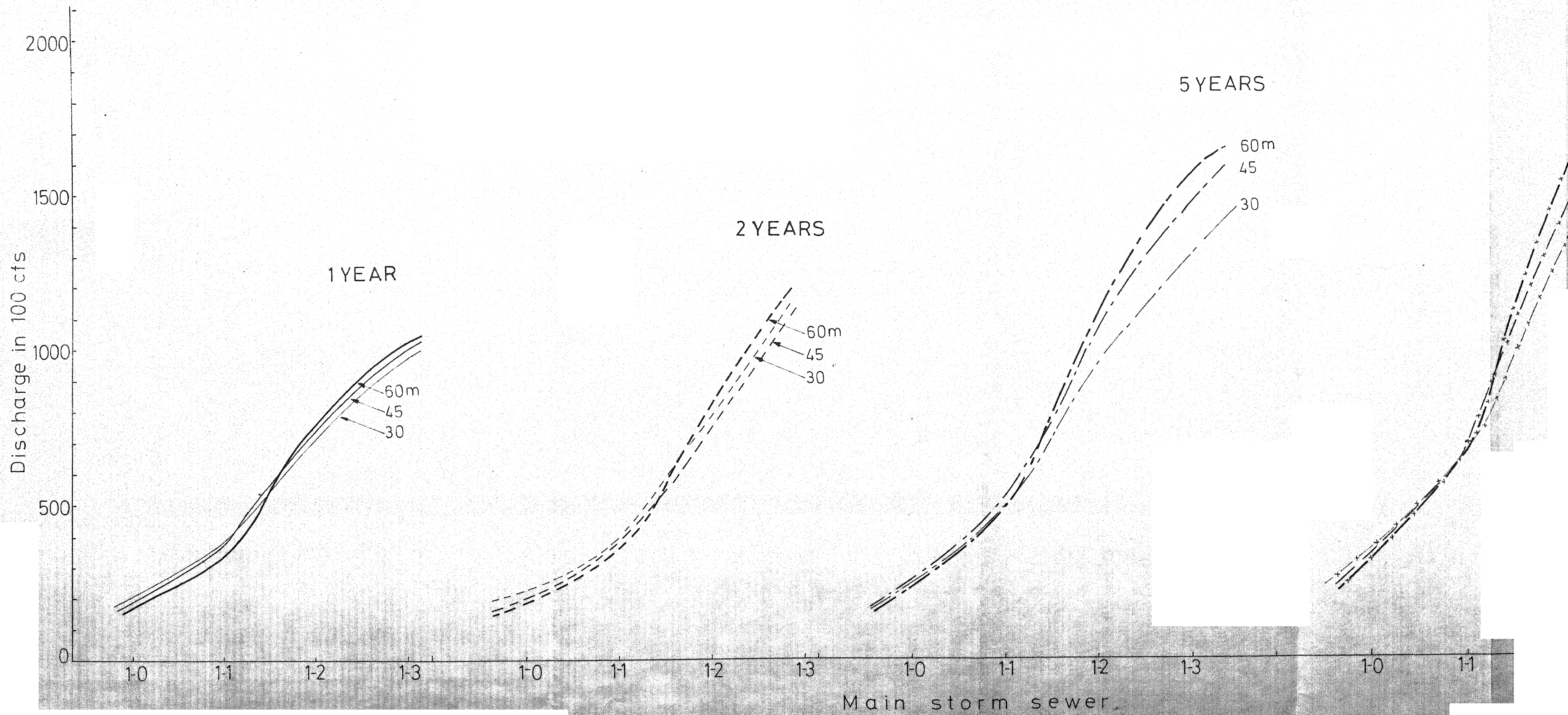
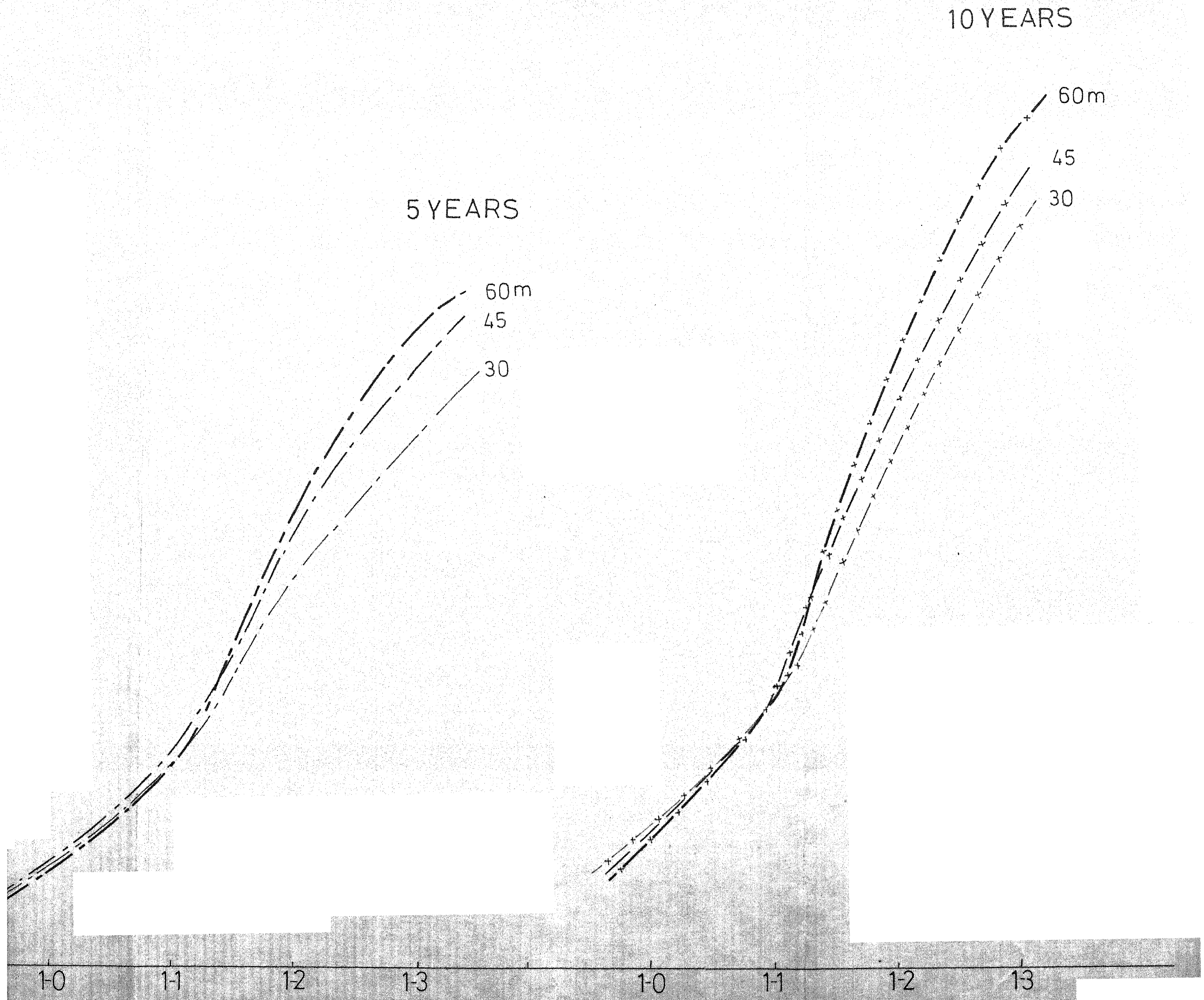


FIG. 4.9 MAXIMUM DISCHARGE ALONG MAIN LINE FOR LUDHIANA


5 YEARS
60m
45
30
10 YEARS
60m
45
30
1·0
1·1
1·2
1·3
1·0
1·1
1·2
1·3

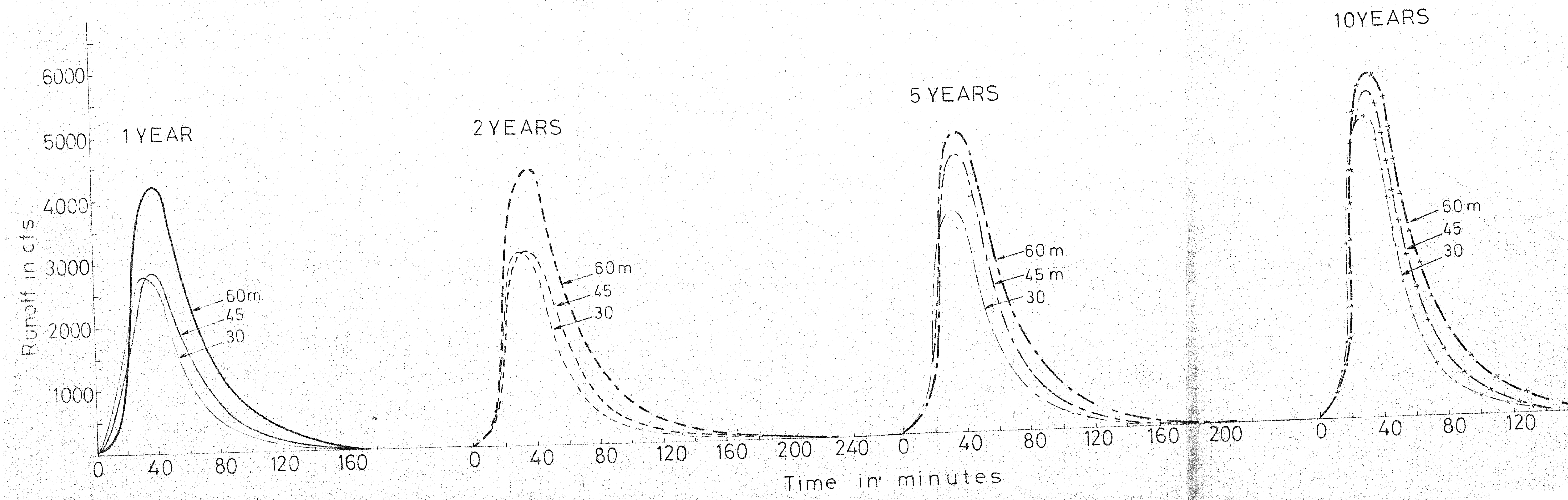
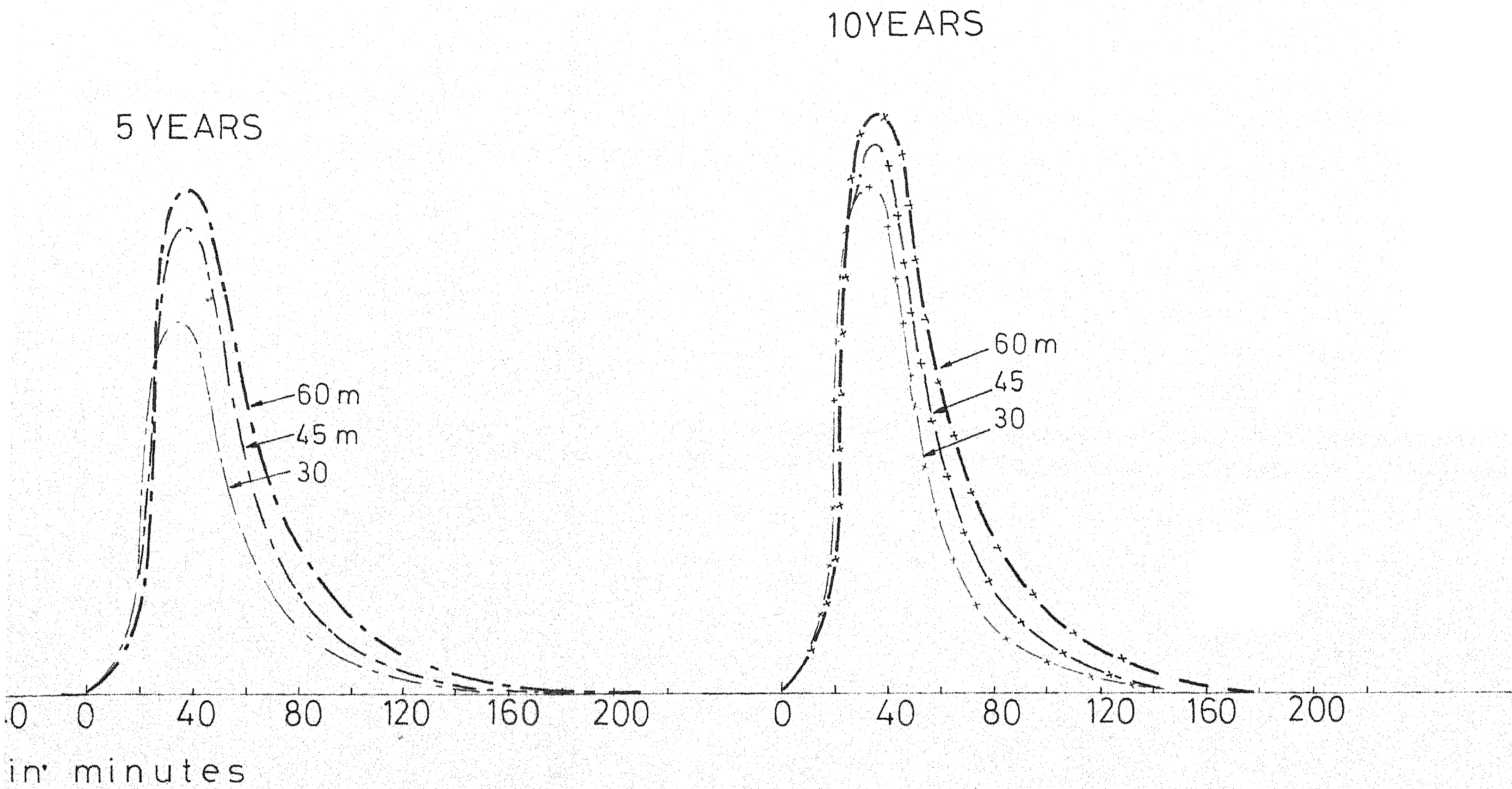


FIG. 4·10 OUTFALL HYDROGRAPHS FOR AMRITSAR



HYDROGRAPHS FOR AMRITSAR

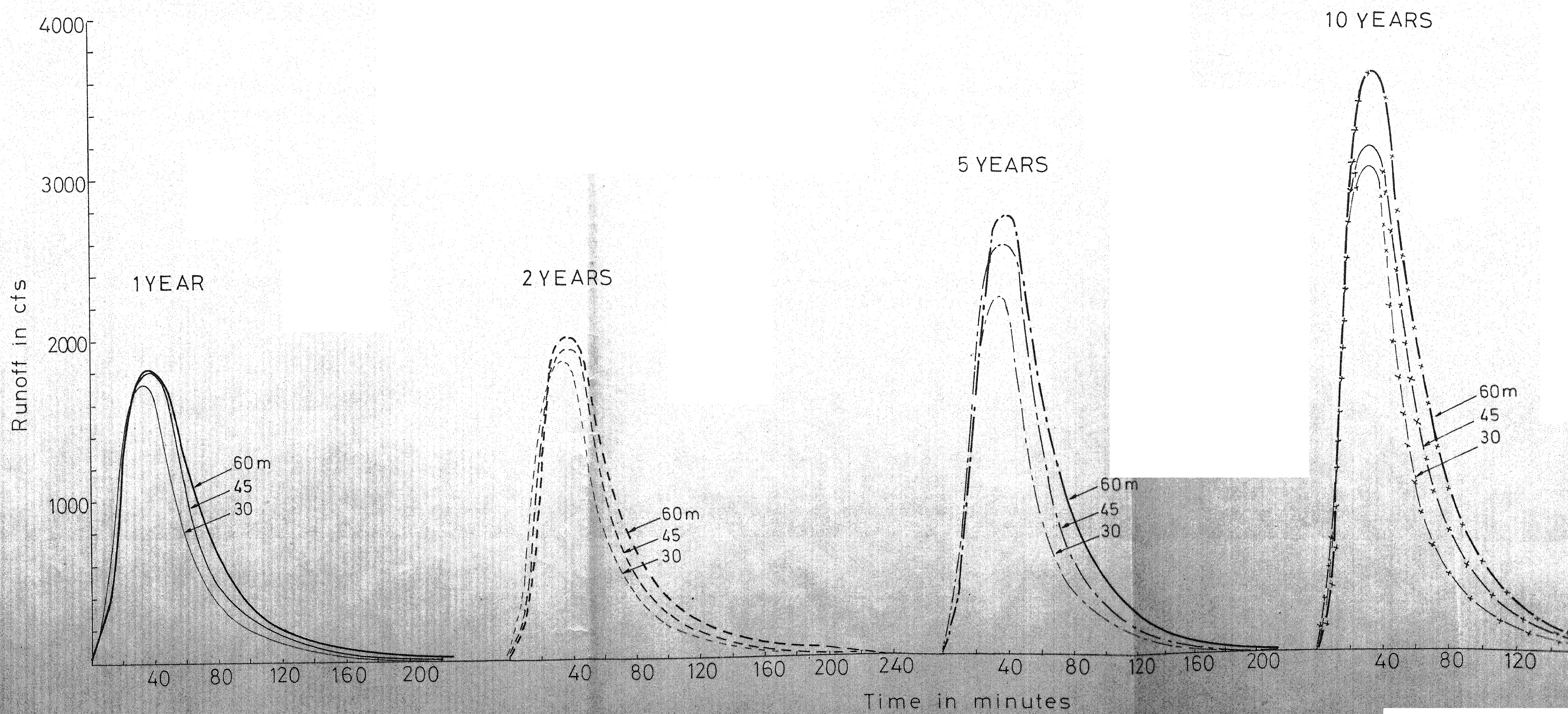
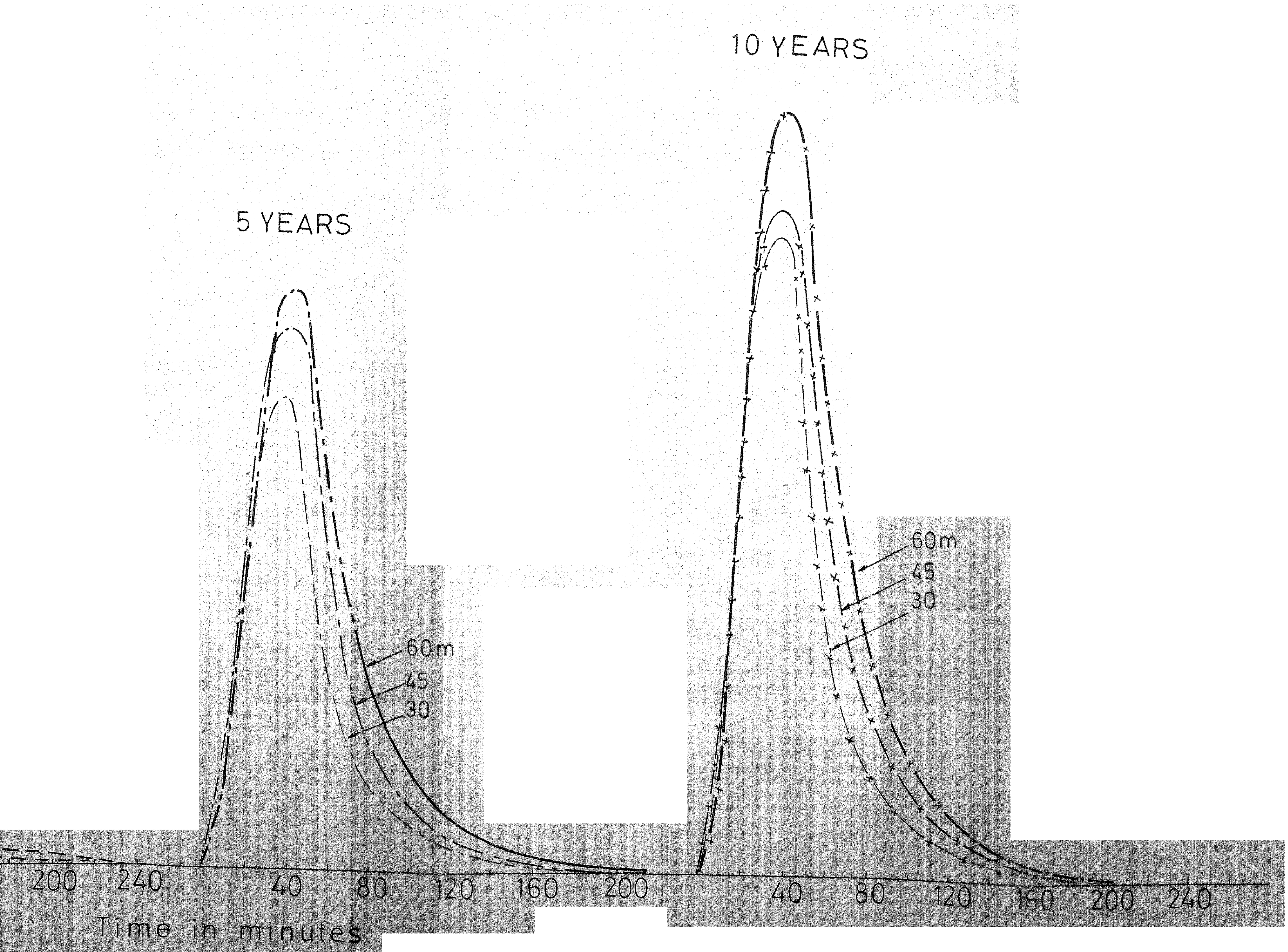


FIG.4.11 OUTFALL HYDROGRAPHS FOR JULLENDHAR



10 YEARS
5 YEARS
60m
45
30
60m
45
30
200
240
40
80
120
160
200
40
80
120
160
200
240
Time in minutes

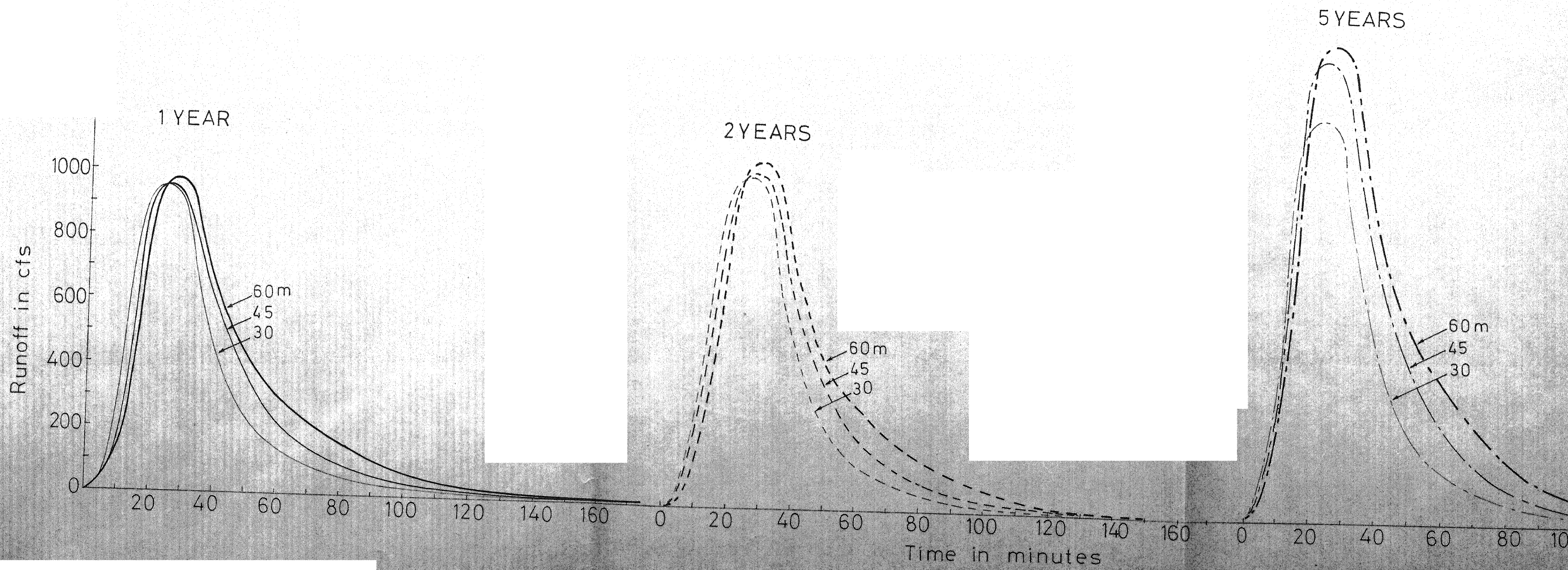
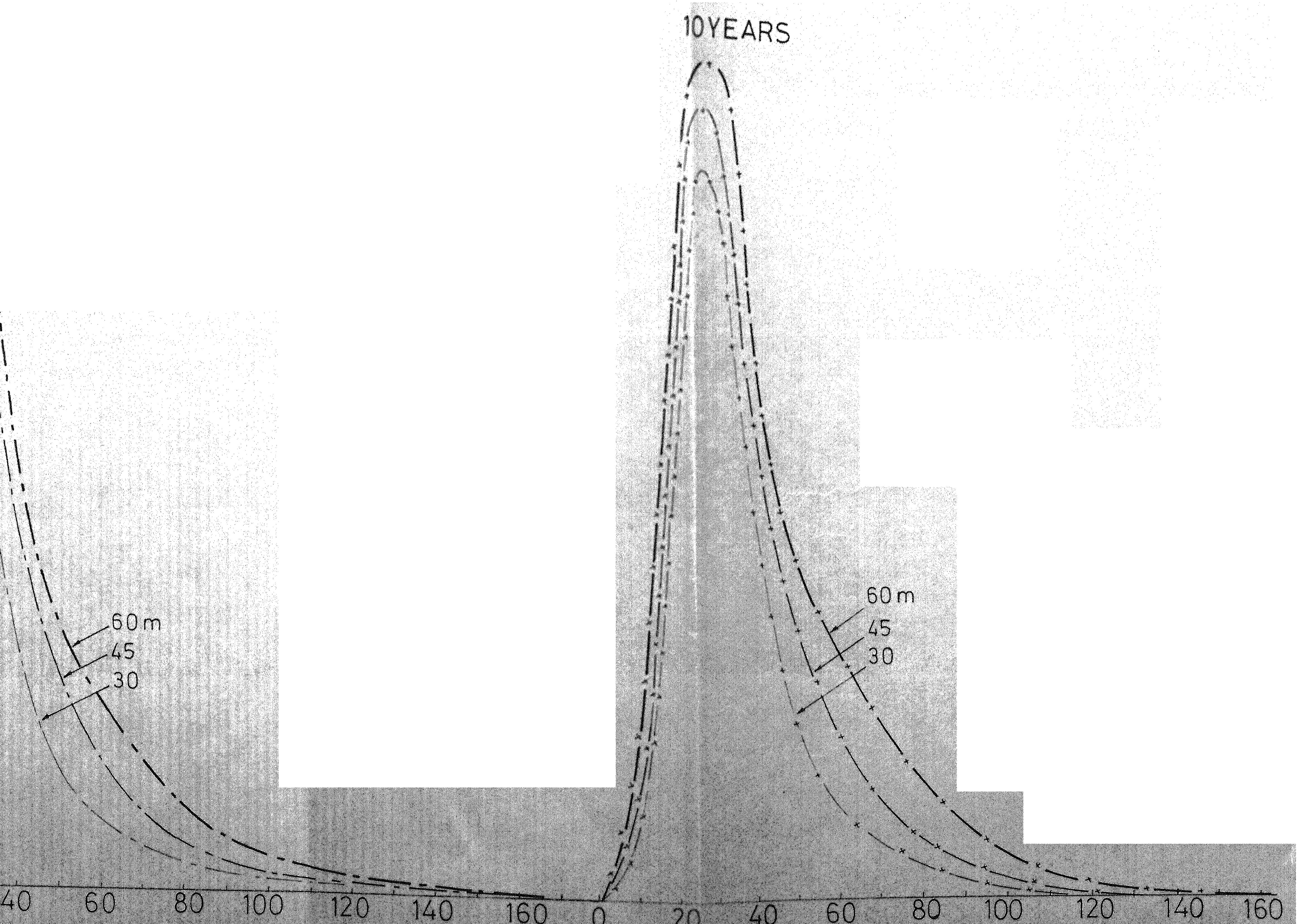


FIG. 4.12 OUTFALL HYDROGRAPHS FOR LUDHIANA



10YEARS
60m
45
30
60m
45
30
40
60
80
100
120
140
160
0
20
40
60
80
100
120
140
160

storages indicated in Subsection 4.4.2 are to be avoided. The peak runoff at the outfall occurs at around 40 minutes indicating that perhaps a larger duration of 1.5 to 2 hours may also have to be considered. It is also noted with a provision of larger diameter, the flat flood peak of the outlet hydrograph is eliminated. But the peak discharges are very much larger varying from around three to four times the results of analysis. A duration of 30 minutes dominates the design for upper reaches while that of 1 to 2 hours may dominate the design for lower reaches.

4.6 Conclusions

The results of this analysis indicate the followings:

i) The U.S. S.C.S. soil type should be B rather than C while the antecedent moisture condition may be class 3 rather than class 2.

ii) Design storm of 1 to 2 hours durations are to be considered with a frequency of 2 to 5 years for design of lower reaches while a duration of 30 minutes may be dominant for upper reaches.

iii) The connected paved areas, unconnected paved areas and contributing grassed areas are to be estimated after field study with great care.

iv) The results of the analysis in this chapter are highly qualitative in nature and should be used with care, if at all, because of the limitations of the study.

5. SUMMARY, CONCLUSION AND SUGGESTIONS FOR FUTURE STUDY

5.1 Summary and Conclusion

With ever increasing urbanization in India there is a great and urgent need for rational economic design of urban drainage systems. Conventionally they are designed by empirical approaches including the rational formula. But the rational method has very serious limitations particularly where diversion from one catchment to another, flood storage, off channel storage, permanent storage, totally impervious catchment, and pumping installations are involved. In such cases it is very much necessary to use urban drainage simulation models for rational and economic design.

There are several computer simulation models available for simulation of urban drainage systems with different assumptions and capabilities. Based on a comparison of the capabilities of the model, their simplicity, availability of data, and a lack of interest in quality simulation, ILLUDAS, a model, developed by Illinois State Water Survey, was implemented in the IBM 7044-1401 Digital Computer System at Indian Institute of Technology Kanpur and was validated with the test data available with original programme (12).

The programme was used to simulate storms of different durations and frequencies in four subsystem of Indian Institute of Technology Kanpur campus drainage system with areas varying from 34.0 to 135.0 acres. The study indicates that a storm of duration of about 30 minute and a frequency of 2 to 5 years may be adopted for design of the systems.

A preliminary analysis of three subsystem of drainage systems respectively for the cities of Amritsar, Jullendhar, and Ludhiana indicated that the upper reaches of the system are to be designed for a duration of around 30 minutes and lower reaches are to be designed for a duration of 1 to 2 hours. A design frequency of 2 to 5 years may be adopted for the system for domestic areas and a higher frequency for commercial areas. It is necessary to identify directly connected paved areas, supplementary paved areas and contributing grassed areas for different reaches of the system before definitive decisions can be taken.

5.2 Suggestions for Future Study

This study is essentially preliminary in nature. It is necessary to collect more details of systems, estimate the parameter much more rigerously and use ILLUDAS for

analysis and design of a number of existing system. It is also necessary that other simulation models also are used with these data. Only than definitive statements concerning the necessity and use of urban simulation

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